

**Beyond Development Corridors: Infrastructure and Uneven Rural
Transformation in Southern Africa**



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Abstract

Infrastructure-led development has made a comeback in recent years with development corridor promoted as a strategy for regional development that aims to connect productions sites to global value chains while promising to attract investment along the route and foster regional economic integration. Critical scholarship challenges this win-win narrative, arguing that development corridors often function as tools of commodity circulation that selectively integrate logistic hubs and production sites, creating extractive enclaves and leaving the areas in between behind. However, most of this literature analyse infrastructure-led development in isolation without considering other overlapping infrastructures. Yet most rural regions are pursuing development corridor alongside other development visions in the same territory. This dissertation therefore aims to examine how corridor-led development produces uneven development focusing on the Walvis Bay Ndola Lubumbashi Development (WBNLDC), a 2500 km transport corridor that connects the copper belt and Katanga region of Zambia and Democratic Republic of Congo (DRC) to the port of Walvis Bay in Namibia via rail and road. Empirically, this dissertation combines remote sensing and household survey with policy and planning documents to characterise the evolution of economic activities along the corridor since its inception. Conceptually, the paper draws from neoclassical economic, critical political economy, assemblage theory and capabilities to develop a multi-scalar framework for analyzing the outcomes of infrastructure-led development. Results revealed that uneven development is produced through three analytical dimensions such as spatial selectivity, infrastructural interaction, and differentiated household capability. The results indicate increased economic and land sue transformation along the corridor is highly unevenly distributed. In Zambezi Region higher land use transformation was found along regional roads than development corridor which suggest that road infrastructure produces differentiated outcomes. Similarly, economic activities along the corridor were found to be tied to global commodity including mining towns, logistic hubs and tourism sector. Further, the analysis of household's proximity to infrastructural assemblage revealed that the interaction among infrastructure can either complement or undermine one another depending on their spatial logic. The analysis also revealed that households experienced the assemblage differently depending on their capabilities. Education and asset ownership determines how access to infrastructure can be converted into

livelihood gains and determine how household transition among livelihood groups. Overall, this dissertation contributes to economic geography and infrastructure-led development by providing a multi-scalar framework for analysing infrastructure-led development and creating an analytical framework that explain uneven development through interaction of spatial selectivity, infrastructural assemblages and household capabilities.

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Abbreviations

AfDB	African Development Bank
CBNRM	Community-Based Natural Resource Management
CCAP	Comprehensive Conservation Agriculture Programme
DCPP	Dryland Crop Production Programme
DFID	Department for International Development
DiD	Differences-in-differences
DMSP	Defense Meteorological Satellite Program
DRC	Democratic Republic of the Congo
GDP	Gross Domestic Product
GEE	Google Earth Engine
GSSP	Graduate School Scholarship Programme
HCI	Human Capital Index
JICA	Japan International Cooperation Agency
LULCC	Land use and landcover change
MPI	Multidimensional poverty index
NDP	National Development Plans
NDVI	Normalized Difference Vegetation Index
NICFI	Norwegian International Climate and Forest Initiative
NTL	Nighttime Lights
OLS	Operational Line-scan System

PCA	Principal Component Analysis
PCNL	Pixel-Scale Corrected Nighttime Light
PIDA	Programme for Infrastructure Development in Africa
PSM	Propensity score matching
SADC	Southern African Development Community
SD	Standard Deviation
SDG	Sustainable Development Goals
TWFE	Two-way fixed effects
VIIRS	Visible Infrared Imaging Radiometer Suite
WBCG	Walvis Bay Corridor Group
WBNLDC	Walvis Bay - Ndola - Lubumbashi Development Corridor
KAZA -TFCA	Kavango–Zambezi Transfrontier Conservation Area
LAPSSET	Lamu Port–South Sudan–Ethiopia–Transport
VIIRS	Visible Infrared Imaging Radiometer Suite

1 Introduction

Infrastructure-led development has risen rapidly as an international development strategy over the last two decades (Schindler & Kanai, 2021). Large-scale infrastructure projects such as roads, bridges, pipelines, railways, ports and dams are being rolled out across the globe as a strategy to shift attention towards spatial planning, connectivity and investments (Schindler & Kanai, 2021; Wiig & Silver, 2019). This shift is driven by a global growth coalition of international institutions, multilateral development banks, and nation states that aim to “get the territory right” through spatial planning and infrastructure strategies for economic growth (Schindler & Kanai, 2021). While these large-scale projects historically served resource extraction (P. R. Carmody, 2017), local governments and multinational corporations now promote them as a win-win strategy that combines regional logistics with broader socioeconomic development. At the centre of this new developmental regime are development corridors. Development corridors are designed to connect peripheral production sites to global markets, attract investments along the corridor and promote regional economic integration (Cox & Hope, 2015; Mulenga, 2013).

Mainstream development policy presents development corridors as a win-win strategy. Grounded in neoclassical economic theory, the framework suggests that improving infrastructure will reduce transportation costs and enhance regional connectivity (Krugman, 1991). The World Bank’s 2009 Development Report, *Reshaping Economic Geography* for example, argues that connecting cities and rural areas along a corridor reduces transport and trade costs, thereby promoting regional integration and fostering the development of economic clusters, thus contributing to poverty reduction (World Bank, 2009). This is expected to automatically integrate hinterlands and foster regional development by creating forward and backward linkages (Morris et al., 2019).

Despite the popularity of development corridors and infrastructure-led development, the literature presents contrasting views on the outcomes of the so-called win-win framework presented by the development corridor agenda (Scholvin, 2021). Empirical realities across Sub-Saharan Africa frequently point to uneven outcomes. This is mainly because development corridors are designed as tools for circulation that selectively integrates resource rich regions into global markets while bypassing the intermediate regions they

pass through (P. R. Carmody, 2017; Enns, 2018; Zajontz, 2024). In reality, they often function as enclaves that create localised winners and losers and exacerbating inequalities (Aalders et al., 2021; Ferguson, 2006; Lesutis, 2019). Some scholars have therefore asked whether these contemporary infrastructures are merely a modern reproduction of colonial legacies (Enns & Bersaglio, 2020).

While existing literature has documented both the positive and negative outcomes of developmental corridor (Alam et al., 2022; Bignoli et al., 2024), a key gap remains. Development corridors are often analysed in isolation from other coexisting regional strategies, such as rural roads, dams, ports, or community-based organisations. Contemporary infrastructure-led development regimes include both 'hard' infrastructure such as transport corridors, rural feeder roads, ports, and dams (Schindler & Kanai, 2021) and 'soft' institutional infrastructure such as community-based organisations like communal conservancies (Hulke et al., 2020; Kioko & Changwony, 2025). Yet, little is known about how these strategies interact to shape developmental outcomes. This is particularly relevant given that all regional intervention strategies tend to produce localised winners and losers. (Mosley & Watson, 2016; Asher et al., 2018; Lesutis, 2019; Fuseini, 2024; Kadhikwa et al., 2026). Understanding these interactions is therefore essential for explaining the uneven patterns of development that emerge when multiple infrastructures and institutions are rolled out simultaneously.

However, measuring developmental outcomes of development corridors remains difficult for two reasons. Firstly, most existing studies rely on macro-level assumptions that use aggregated measures such as increased trade and total value generated as indicators of development. While development corridors may raise trade and GDP, these increases often fail to account for how benefits translate into local economic activity and livelihoods (Dzumbira et al., 2017; Faber, 2014). As a result, there is a call for studies to focus on wider economic impacts beyond macro trade aggregates, evaluating how localised actors and poorer populations are impacted (Alam et al., 2022). Secondly, existing literature tend to analyse infrastructure-led strategies in isolation. At the same time development corridors are never implemented in isolation; they overlap with existing infrastructure, land use tenures and institutions (Fuseini, 2024; Kioko & Changwony, 2025; Schindler &

Kanai, 2021). In Southern Africa for instance, they intersect with both hard and soft infrastructure, which operate under distinct and sometimes conflicting logics, that can influence the developmental outcomes (Kalvelage et al., 2021; Kioko & Changwony, 2025). For instance, the introduction of development corridors in communal areas of Kenya has restructured land availability and property rights, leading to conflicts among the population (Kioko & Changwony, 2025). However, such complex dynamics are often overlooked and receive less attention in infrastructure-led development studies. Therefore, analysing development corridors in isolation from rural roads or communal programs, such as communal conservancies, does not give the full picture of the area in question.

Lastly, analysing the impacts of development corridors across international borders is hindered by a lack of comparable transnational data. This is particularly worse in African countries where national datasets are often incomplete or unreliable (Storeygard, 2016). Assessing corridor-wide dynamics requires moving beyond fragmented national census reports to use datasets that are methodologically comparable across national boundaries and capable of capturing regional transformation across different spatial scales. To overcome these data deficits, recent economic geography literature has adopted remotely sensed data and complemented it with household level analyses (Henderson et al., 2012; Xiao et al., 2024; Zheng, 2025). This dissertation employs a similar multi-scalar approach to examine how development corridor produces uneven development through the following research objectives:

- a) To analyse patterns of development along the corridor and explain how uneven development emerges at regional and corridor scales.
- b) To examine how proximity to the infrastructural assemblage (development corridor, regional roads and communal conservancies) interacts with differentiated household capabilities to produce uneven livelihood outcomes.

To address these research objectives, this dissertation focuses on the Walvis Bay Ndola Lubumbashi Development Corridor (WBNLDC) as its primary empirical study area. Spanning approximately 2,500 kilometres across Namibia, Zambia, and the DRC, the WBNLDC is a transport corridor connecting the mineral-rich regions of the Zambian and

DRC Copperbelt directly to the port of Walvis Bay in Namibia and the global market (Walvis Bay Corridor Group [WBCG], 2024). The corridor aims to attract investment in agriculture, tourism and manufacturing, as well as fostering regional integration along the corridor (Aurecon, 2014). It traverses diverse land use systems and passes through the Zambezi Region of Namibia, which serves as a central empirical site for this dissertation. The Namibian government has actively promoted the Zambezi Region as a future logistics hub for Namibia and Southern Africa. It is framed as an intersection for agriculture, tourism, and nature conservation where regional development visions are expected to materialise. This study therefore zooms into the Zambezi Region to evaluate how these ambitions for development have unfolded since the strategic completion of the corridor in 2004. This is marked by the opening of the Katima Mulilo bridge over the Zambezi River into Zambia, which enabled corridor's full operations.

This dissertation combines remote sensing, household surveys and policy reports to examine how development evolves along the corridor. It contributes to the debate on infrastructure-led development by conceptualizing development corridors as part of an infrastructural assemblage and analyzing how jointly they produces uneven development. Specifically, it analyses land use transformation and economic patterns along the corridor and examines how the overlapping infrastructure shape rural livelihoods at household level.

The rest of the dissertation is structured as follows: Chapter 2 provides a comprehensive literature of the concepts and theories that guided this study across the three empirical papers. This section digs deeper into current debates on infrastructure-led development, drawing on critical political economy and economic geography to characterise the evolution of development corridors and their developmental outcomes. Specifically, the study employs neoclassical economics to understand the promises of development corridors, political economy literature to characterise the observed patterns of economic activity along the corridor, and lastly assemblage theory to explain how overlapping infrastructure jointly shapes livelihood outcomes. Chapter 3 presents the methodological approach used in this study, ranging from spatial analytical methods to econometric frameworks. Chapters 4, 5, and 6 present the main findings in the form of research

articles. Lastly, Chapter 7 presents a synthesis combining the study's empirical and conceptual findings, as well as the policy implications for regional development and future research.

2 Conceptual Framework: Infrastructure-led development in Southern Africa

In this section, I introduce the conceptual framework that guides the dissertation. This chapter argues that development corridors produce uneven rural transformation because they are spatially selective and mediated by overlapping infrastructures, territorial institutions, and household capabilities. Firstly, I provide an overview of the evolution of infrastructure-led development and its promises. Here I dive into the theoretical assumptions guiding the new rush of infrastructure-led development as expected by neoclassical economics. Secondly, I draw from political economy literature to explain why corridor development is often selective and uneven. Thirdly, I discuss how infrastructure-led development manifests in the reality of overlapping infrastructure in Sub-Saharan Africa. Finally, I present a concluding analytical framework that explain how development corridors produces uneven development.

2.1 Re-emergence of Infrastructure-led Development in Africa

Over the last two decades, infrastructure-led development has risen to the forefront of African development policy. However, the core logic of infrastructure-led growth is not new; its foundational ideas have deep historical roots on the continent. Its key concepts and ideas have always been there. During the 19th-century European scramble for Africa, colonial governments primarily build roads and railways to serve their own economic and geopolitical interests (Jedwab et al., 2017; Kirshner & Baptista, 2023). These infrastructure investments were strategically planned to target mineral-rich hinterlands and areas of high agricultural potential to export raw materials to the industrialised world (Michalopoulos & Papaioannou, 2020). This extractive logic is clearly reflected in the spatial orientation of 19th-century colonial railway networks, which were designed to run directly from inland mining regions to coastal ports rather than connecting domestic cities or integrating local regional economies (Michalopoulos & Papaioannou, 2020). These networks highlighted the colonial priority of resource extraction over domestic territorial integration. Although much of this physical infrastructure fell into bad shape during the post-independence era, infrastructure-led strategies are currently resurfacing across the globe, and most prominently across Africa. This contemporary boom is frequently

described as the “new scramble for Africa” (P. R. Carmody, 2017), raising critical questions about whether these new infrastructure networks differ from their colonial predecessors or if they truly foster inclusive regional development.

In the context of infrastructure-led development, this resurgence leverages spatial planning strategies aimed at “getting the territory right” (Schindler & Kanai, 2021). One such strategy is the development corridor, which gained popularity in Southern Africa. Development corridors are designed to connect production sites to global markets while simultaneously attracting investment along the route to foster economic integration and regional development (Mulenga, 2013). This idea gained particular traction in international development policy following global financial crisis of 2008, when the World Bank's 2009 World Development Report: Reshaping Economic Geography argued that deliberate investment in both hard and soft infrastructure is central to economic growth, because it lowers transaction costs and enables market integration (World Bank, 2009). The report drew on Paul Krugman's “New Economic Geography”, which explains how transport costs, market access, and increasing returns to scale interact to produce uneven spatial concentrations of economic activity (Krugman, 1991). The concept of infrastructure-led development is to take advantage of the investor's need to transport raw materials to global markets and induce growth in areas surrounding the corridor (Dannenberg et al., 2018; Enns, 2018).

It is expected that this process will translate into regional development through four key neoclassical mechanisms: connectivity, investment attraction, agglomeration, and regional spillover.

Based on the neoclassical thinking, the most important starting mechanism of infrastructure-led development is connectivity. Infrastructure is expected to reduce transportation costs, eliminate bottlenecks, and integrate regional markets (Mulenga, 2013). The underlying assumption is that economic actors may make rational decisions in their own best interest (World Bank, 2009), once given the right information. Those along the corridor, such as farmer, are expected to seize the opportunity of lower transport costs and better market access to target even larger markets.

Once connectivity has been established, the resulting reduction in transport and coordination costs is assumed to lower overall investment risks (Aschauer, 1989; Graham, 2007). This may, in turn, attract new Foreign Direct Investment (FDI), a phenomenon known as the "crowd-in" effect (Aschauer, 1989). As firms anticipate to move inputs and outputs more cheaply, expected financial returns will increase. Higher expected profits will encourage new FDI and firms to set up along the route. Basic infrastructure such as water and telecommunications networks are expected to naturally follow to support these new investments and firms (Ingram et al., 1994; Schindler & Kanai, 2021).

New investments is expected to generate agglomeration, which is the third mechanism of infrastructure-led development. Areas connected by corridors are expected to become attractive to investors, resulting in firms clustering to benefit from shared infrastructure, skilled labour, and local spillovers (Glaeser, 2010; World Bank, 2009). As a result, more related industries will open up to new businesses, creating a self-reinforcing loop. This could then enable firms to share production costs, establish a division of labour, and generate economies of scale (Aggarwal, 2020; Pokharel et al., 2023). These economies of scale encourage more firms and regions to specialise and produce efficiently, thereby increasing their productivity scale (Dannenberg et al., 2018; Enns, 2018; Lafourcade & Thisse, 2011; Puga, 2010). Together, this agglomeration of economic activities creates a complete local production complex consisting of primary production, processing, packaging, and distribution along the new transport route (Breul & Revilla Diez, 2021).

Lastly, the integration of economies will facilitate the movement of capital and people (Krugman, 1991; Pokharel et al., 2023). People are expected to migrate toward the cities (nodes) and rural areas in between, leading to capital accumulation, increased labour force, and knowledge transfer processes (Krugman, 1991; Puga, 2010). These agglomerations will generate spillovers to surrounding areas, thereby reducing regional disparities and fostering regional integration (World Bank, 2009).

According to this logic, infrastructure-led development and development corridors are theorized to follow a progressive development path that evolves from a basic transport corridor to a logistics and trade corridor before reaching an economic growth corridor,

where regional spillovers and broad based economic growth are anticipated (Brand, 2024; Gálvez Nogales, 2014). However, critics of infrastructure-led development argue that corridors often facilitate for resource extraction leaving the area inbetween behind rather than fostering the equitable growth they were intended to achieve (Dannenberg et al., 2018; Lesutis, 2019; Scholvin, 2021).

2.2 Critical Perspectives: Selectivity and Uneven Development

Despite the positive narrative promoted by mainstream development policy discourse, recent political economy scholars have challenged the win-win narrative of the contemporary development corridor agenda. They argue that infrastructure-led development frequently reinforces spatially uneven and socially selective patterns of accumulation rather than resolving them (Dannenberg et al., 2018; Enns & Bersaglio, 2020). Much of this literature frames corridors as a "spatial fix" (Zajontz, 2023; Harvey, 1981), designed to resolve the crises of overaccumulation in global economies by getting the territory right for efficient extraction and circulation of raw materials toward the global value chains (Lesutis, 2019; Schindler & Kanai, 2021). Consequently, corridor development rarely generates inclusive, widespread economic growth; instead, it produces spatial "winners and losers", reinforcing extractive enclaves and deepening regional inequalities (Müller-Mahn et al., 2021; Scholvin, 2021). This section identifies the interacting mechanisms behind this selective pattern.

Firstly, development corridors are selectively planned and governed. As they typically span multiple nation states with distinct governance structures, corridors can present challenges in terms of coordinating economic development policy. Although corridor management groups are created to promote seamless, frictionless movement, each nation-state prioritises its own strategic and territorial interests. As Zajontz (2024) demonstrates, this dynamic often leads to conflicting state agendas and regional friction, (Zajontz, 2024) which often results in a contested and highly fragmented governance system that hinders overall developmental expectations. Even if a corridor manages to "get the territory right" and attract investment along the route, corridor level central planning still operates at different scales and spatial distances from localised realities (Schindler & Kanai, 2021). Development corridor operations involve critical contextual

issues that demand harmonized cross-border coordination. However, such top-down spatial planning rarely accounts for the street-level politics and localised institutional realities that govern space in the Global South (Bayat, 2000; Schindler & Kanai, 2021).

Secondly, corridors reorganise space in a way that prioritises nodes and logistics over the surrounding territory. Many contemporary development corridors in the Global South are built upon colonial transport frameworks legacies, thereby reproducing historical racial and spatial hierarchies those frameworks were designed to serve. The planning and financing of these projects are driven by these frameworks, which often perpetuate racialised power dynamics (Kimari & Ernstson, 2020). This results in the recreation of historic spatial imbalances without changing the underlying socioeconomic structures. This is rooted in the structural design of development corridors, as they are designed to prioritise integrating resource frontiers into global production networks by selectively targeting specific strategic nodes such as ports, production sites, and logistics hubs while bypassing surrounding communities (Schindler & Kanai, 2021). As they prioritise velocity and logistics security, they end up functioning as pipelines connecting resource enclaves directly to the ports while bypassing local areas in the process (Tassadiq et al., 2025). By prioritising movement of commodities to foreign markets, they inevitably create distinct spatial and social “winners” and “losers”. This creates divisions among local populations; for example, “non-modern” or mobile groups, such as pastoral herders in Kenya, are actively excluded, settled, or restricted in their daily mobilities by the high-speed transit logic of the corridor (Aalders et al., 2021).

Thirdly, corridor development do not only produce spatial inequalities but also differentiated social outcomes. When megaprojects are introduced in this context, they interact with both existing customary land tenure and local environmental regimes. This interaction can trigger land speculation and raise land values, resulting in highly uneven outcomes and elite capture of economic benefits (Kioko & Changwony, 2025). This can lead to dispossession and marginalisation of local communities. Development corridors reorganise territorial access and resource control and thus can control who benefits from improved connectivity and who suffers from displacement (Lesutis, 2021). The outcome

is thus not only uneven development across space but uneven across households and social groups.

Overall, outcomes of development corridors are shaped by different mechanisms of selectivity that operate across scales and over time. The next section extends this discussion by showing how corridor outcomes are further mediated by interactions with other infrastructures and household capabilities

2.3 Beyond the Corridor: Infrastructural Assemblages and Differentiated Capabilities

The prior discussion of the political economy of corridors highlights how infrastructure-led development is envisioned and experienced in the Global South. This calls for attention to what happens "beyond connectivity"; specifically, how physical transport networks interact with complex territorial institutions and heterogeneous socioeconomic contexts to produce uneven development. Infrastructure is never introduced into a vacuum and its broader developmental impacts cannot be evaluated without examining these relational interactions (Hudalah, 2026; Larkin, 2013). Large-scale corridors span vast regions, cross diverse landscapes and land use systems which fundamentally alter how infrastructure is used and who benefits from it. To capture this complexity, an infrastructural assemblage approach is adopted. Assemblage thinking offers a relational framework that treats infrastructure-led development as a dynamic configuration of socio-material components that collectively shape spatial and developmental outcomes (Hansen & Schulze, 2021; Hudalah, 2026).

From an assemblage perspective, development corridors are not standalone infrastructures that automatically induce regional growth. Rather, their outcomes depend on how they interact with other components that make up the assemblage (Hansen & Schulze, 2021). In Southern Africa, corridor intersect existing infrastructure networks, such as regional and rural feeder roads, as well as environmental governance structures that are themselves territorial and highly contested (Kioko & Changwony, 2025). The developmental outcomes of a corridors are therefore shaped by how the spatial logics of these overlapping "hard" and "soft" infrastructures interact within a space. These

interactions can be complementary or conflictual, depending on the compatibility of each infrastructure's spatial logic.

Infrastructure-led development operates under neoclassical economics, assuming that lowering transactional costs will encourage the actors to diversify and transition into commercial markets (Schindler & Kanai, 2021). Regional and rural roads, for instance, aim to connect rural populations to markets, on the assumption that improved connectivity will incentivise farmers to transition from subsistence to commercial production (Hine et al., 2019). Development corridors follow a similar yet distinct logic. Designed as high-capacity and long-distance routes, development corridors connect strategic production sites to global markets and attract investment across sectors including agriculture, manufacturing, logistics, and tourism (Mulenga, 2013). While rural roads are intended to broaden local market access, corridors are intended to accelerate the movement of commodities and capital across national and regional scales. This distinction is important because infrastructure can reorganise the surrounding economic and territorial relations, generating wider processes of land speculation and land use transformation (Gillespie & Mwau, 2024). An assemblage framework allows for a comparative analysis of this hard infrastructure, revealing how their various spatial logics interact or complement each other, and identify which configurations are most conducive to regional and corridor-wide development.

Development corridors in Southern Africa also overlap with soft infrastructure. An example is the environmental infrastructure governed under the Community-Based Natural Resource Management (CBNRM) programme, such as communal conservancies. Communal Conservancies regulate the use of natural resource and connect them to global tourism value chains for rural livelihood improvements (Bollig & Krause, 2023; Kioko & Changwony, 2025). These environmental infrastructures consist of various rules on how land is to be utilised, including prioritisation of conservation and allocating land use zones of various land uses within the regions, such as agriculture, recreational use or animal use (Jones et al., 2015). Therefore, it is important to understand how the logics of regional roads, development corridors and conservancies interact within the same territory and how this shapes livelihood outcomes. An

assemblage approach demonstrates that rural development pathways in these spaces are never the product of a single infrastructure in isolation, but are instead reconfigured by the interactions of hard and soft infrastructural components.

However, analysing infrastructural assemblages alone primarily explains spatial variations across landscapes; it does not explain why households residing in the same village with similar access to the infrastructure experience different socioeconomic outcomes. Literature on assemblages shows that infrastructure outcomes are shaped by human and non-human factors. A livelihood perspective can help to bridge this gap by explaining how capabilities are used to produce outputs (Dorward et al., 2009; Hulke et al., 2020; Scoones et al., 2012). Therefore, integrating a livelihood framework into the infrastructural assemblage perspective helps to explain how households use their resources and assets to take advantage of improved access to markets and other opportunities. The framework recognises that households differ in their livelihood strategies according to their main sources of livelihood. In this study, households are grouped into three livelihood typologies. Subsistence-oriented households mainly use agricultural output for their own consumption. Farm-market households use agricultural production both for consumption and income generation. Non-farm or diversified households combine farming with other sources of income, such as wage employment, business activities, or other non-farm activities.

Households can use their available assets and resources to move between these livelihood strategies. Such livelihood transitions are commonly described as “hanging in,” “stepping up,” “stepping out” and “Dropping out” (Dorward et al., 2009; Hulke et al., 2020; Pritchard et al., 2017). These strategies and definitions have been adapted to our case study. Hanging in refers to households that remain in subsistence-oriented farming and seek to maintain their current livelihood. Stepping up refers to households that move from subsistence-oriented farming towards farm-market livelihoods by engaging in increased production and market participation of their main source of livelihood. Stepping out refers to households that look to diversify their livelihood by focusing on additional sources of income such as formal employment or businesses. Dropping out refers to households that experience a decline in their economic well-being and downward mobility (ibid). Using

this framework makes it possible to examine whether proximity to different parts of the infrastructural assemblage supports households to maintain, improve, or diversify their livelihoods.

2.4 Analytical Framework

To analyse infrastructure-led development, this dissertation conceptualises development corridors as part of an infrastructural assemblage. The outcomes of development corridors in terms of economic activity, regional development, and rural livelihoods are the result of interacting components of the infrastructural assemblage and household capabilities. To guide this analysis, the analytical framework brings together three core dimensions: spatial selectivity, infrastructural interactions, and differentiated capabilities which explain the outcomes of these development corridors as explained in Table 1 and Figure 1.

Table 1: Mechanisms shaping development outcomes along development corridors

Mechanism	Corridor-wide integration and agglomeration	Selective integration and extractive enclaves
Spatial Selectivity	- Growth is balanced across the corridor - Areas in between hubs are connected and show development - The corridor strategically connects areas in ways that produce even development across the corridor	- Growth is concentrated in extractive and logistics hubs - Area between the nodes see little to no growth - The corridor strategically connects production sites and hubs that are tied to global commodity chains
Infrastructural Assemblage	- Infrastructure is strategically aligned	- Infrastructure is misaligned

	- Infrastructure logics are complementary and reinforcing each other	- Infrastructure logics are competing and conflictual
Household Capabilities	- Households have the necessary skills and assets to convert access into livelihood - Households receive training and support to build necessary assets - All households are positioned to benefit from improved access	- Households lack the assets or skills to convert access into livelihood improvements - Households receive little or no training or support - Only better-off households benefit from improved access

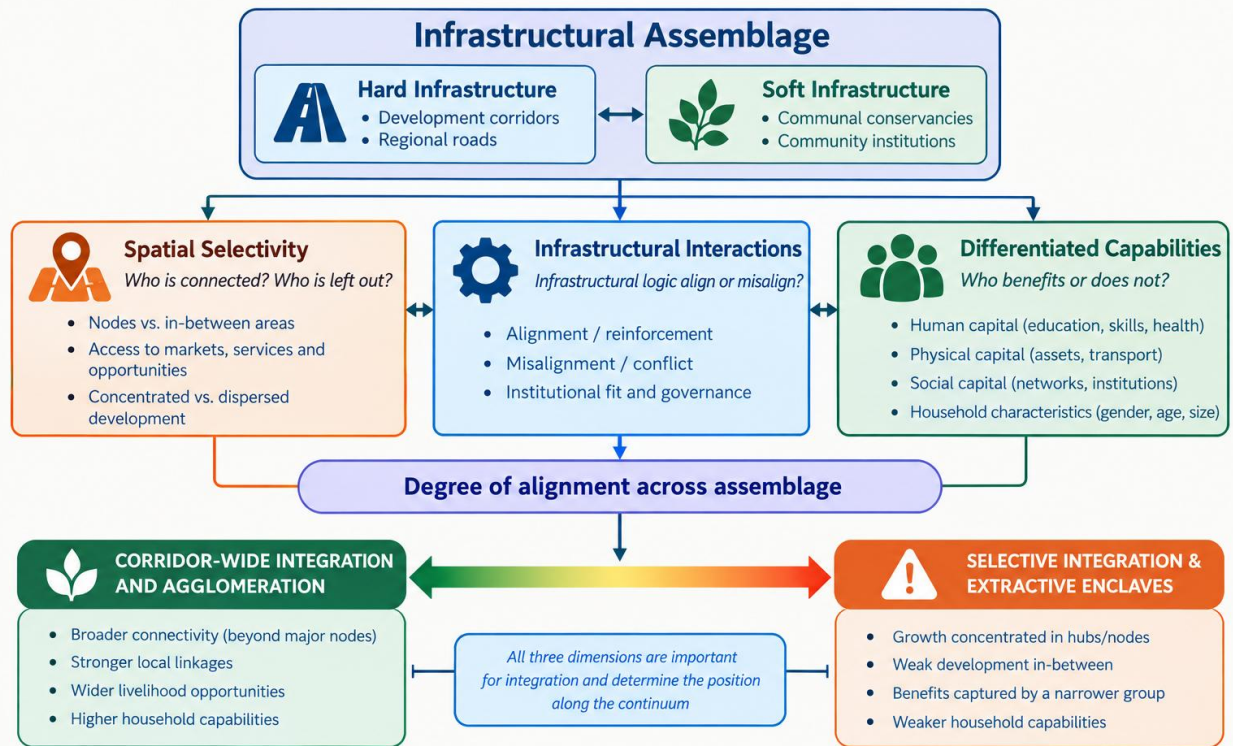


Figure 1: Infrastructural assemblages and the production of uneven development along the development corridors

Spatial selectivity draws on political economy to explain how development corridors and infrastructure-led interventions selectively organise territories. Corridors are introduced into existing territories where they target specific strategic nodes to plug them into global value chains under the promise of broad-based regional growth (Schindler & Kanai, 2021). In practice, however, they primarily construct high-speed channels for the rapid extraction and circulation of commodities (Tassadiq et al., 2025). This gives rise to enclave economies and generates "winners and losers" as new actors enter and reconfigure the landscape. In the empirical analysis, spatial selectivity is analysed through comparisons of places that are directly targeted by corridor investments versus those that are bypassed or only indirectly connected. The observed patterns will explain how uneven development or corridor-wide agglomeration is produced along the corridor.

Infrastructural interactions are concerned with what happens when large-scale projects enter these contested territorial spaces. In some cases, it leads to collisions between

existing institutions and overlapping infrastructure. As literature frames infrastructure as a dynamic, relational, and dependent on socio-material configuration, the outcomes of infrastructure-led development are continuously shaped by pre-existing structures, including governance frameworks, customary institutions, and regional road hierarchies available in space (Hudalah, 2026). In the empirical analysis, this dimension is analysed through comparisons of households in different infrastructural assemblages such as corridor and conservancy versus corridor and district road and how these interactions shape livelihood outcomes.

Differentiated capabilities refer to the varying ability of households to capitalise on increased physical access to infrastructure. Mainstream infrastructure-led development assumes that all local actors will automatically benefit from enhanced connectivity, either through commercialising agricultural production or transitioning to new economic opportunities (World Bank, 2009). However, capability frameworks demonstrate that physical access is merely an external resource. A household's internal capability set determines how that access is utilised and converted into meaningful economic well-being (Dorward et al., 2009). In the empirical analysis, differentiated capabilities are analysed through household level panel data that capture changes in human capital, households' assets and how these interact with infrastructure access to shape livelihood typologies and transition over time.

Overall, these three analytical dimensions provide the conceptual tools to explain how development corridors produce spatially uneven and socially selective outcomes, rather than the corridor-wide, inclusive regional development envisioned by mainstream infrastructure-led growth strategies. Reaching broader corridor-wide development requires a favorable condition across all three mechanisms. These dimensions are used to interpret findings from the three empirical papers. Spatial selectivity is examined through the patterns of land use transformations and economic activities in paper 1 and 2, meanwhile infrastructural assemblages and differentiated household capabilities are examined at household level in paper 3. The analytical framework is further discussed in detail in Chapter 7 of the dissertation.

3. Research Methodology

Evaluating the developmental outcomes of transnational transport corridors presents a complex analytical challenge. This is primarily because development varies across different spatial scales and large-scale infrastructure projects, such as development corridors, are never implemented in isolation, but are shaped by other coexisting development interventions and land tenure systems. To account for these overlapping dynamics, this dissertation employs a mixed methods spatial research design integrating satellite remote sensing, spatial econometric analytics, primary household surveys, and policy document analysis. The remote sensing analysis enables large-scale, cross-border assessment of the corridor and maps its historical spatial transformation over time. Household level surveys are also used to provide a micro-level analysis of local communities along the route. In addition to the development corridor itself, the study looks at other prominent development strategies being implemented in the region, such as communal conservancies and rural roads. This allows us to understand the synergies and trade-offs that emerge from their interaction. Relevant policy reports and official planning documents were incorporated into the analysis. This approach provides a comprehensive overview of the spatial transition and offers a clearer explanation of how development has evolved along the corridor.

3.1 Setting the Scene: Case Study Selection

The WBNLDC is a compelling case study for the developmental outcome of a development corridor. Spanning approximately 2,500 kilometres of rail and road across Namibia, Zambia, and the DRC, the corridor connects the Copperbelt region of DRC and Zambia to the port of Walvis Bay in Namibia and further to the global market. This corridor is a strong empirical case primarily because the Namibian government has deliberately pursued a proactive "regional gateway approach," using the WBNLDC and the Zambezi Region as a key instrument to achieve regional integration and economic growth (Zajontz, 2024). Analysing this corridor reflects the substantial commitment and investment made to transform it into a functional, dual-purpose trade route for regional development.

The WBNLDC was constructed in two main phases. Phase I concluded in 1999 with the official opening of the newly tarred Trans-Caprivi Highway between Windhoek and the Zambezi Region (formerly the Caprivi Strip). Following Namibia's independence in 1990, the Zambezi Region remained geographically and economically isolated from the rest of the country (Colpaert et al., 2013). Paving the highway connected the region to the capital city was intended to integrate its local economy with that of the capital (Zeller, 2009). After this internal connection was established, Namibia and its neighbouring countries expanded the trade network in phase II to foster cross-border logistics. This phase concluded in May 2004 with the official opening of the bridge over the Zambezi River at the Wenela border post between Namibian town of Katima Mulilo and the Zambian town of Sesheke at the border. The bridge replaced an inefficient ferry system and enabled heavy freight vehicles to move seamlessly between Namibia, Zambia, and the DRC. This prompted an expansion in cross-border logistics and trade volume along the WBNLDC (Esser, 2017). The WBNLDC also aims to attract investment in strategic sectors such as tourism, agriculture, manufacturing, and logistics along the route (Aurecon, 2014).

After completing of the bridge, the Namibian government identified the Zambezi Region as a key hub and began to promote the region as a strategic logistics centre for Southern Africa (Japan International Cooperation Agency (JICA), 2015). This makes it a suitable site for a localised, smaller-scale analysis within this dissertation. Conducting local empirical analysis in the Zambezi Region enables this dissertation to examine how these ambitions have materialised on the ground over the two decades corridor the corridor was finalised in 2004.

Beyond transport infrastructure, the Zambezi Region is characterised by overlapping spatial agendas of infrastructure, conservation and tourism making it a unique empirical setting. The Zambezi Region is strategically situated at the heart of the Kavango–Zambezi Transfrontier Conservation Area (KAZA TFCA). KAZA is the largest transboundary conservation area in Southern Africa that spans parts of Namibia, Angola, Zambia, Zimbabwe, and Botswana (Bollig & Krause, 2023). This conservation initiative aims to protect biodiversity while simultaneously generating benefits for the populations living within the landscape. In Namibia and across Southern Africa, this conservation logic

is institutionalised through governance frameworks such as the CBNRM policy (Jones et al., 2015). The core principle of CBNRM is to decentralise the management of natural resources to local communities living near them, enabling these communities to navigate the associated costs and benefits of the wildlife and environmental management (Heffernan, 2022; Welch, 2018). In addition to KAZA, communal land in the Zambezi Region comprises of various conservation initiatives, including communal conservancies, community forests, and national parks. Together, these function as what Bollig and Krause (2023) term "environmental infrastructure" or broadly as "soft infrastructure," as referred to throughout this dissertation. This soft environmental infrastructure operates within defined spatial boundaries, establishing rules for resource use, land allocation, and wildlife protection to support conservation goals, economic development, and community welfare (Heffernan, 2022). Given these coexisting initiatives, the Zambezi Region stands out as a key setting for both conservation and nature-based tourism. These overlapping logics of transport infrastructure, conservation, and tourism make the Zambezi Region an empirically compelling site for this dissertation.

3.2 Methodological Approach

The present dissertation is built upon the empirical findings and conceptual frameworks developed during Phase I (2018–2021) of the CRC TRR 228 Future Rural Africa – Future in Chains sub-project. Focusing on development corridors, phase I findings highlighted how governments encourage development corridor growth alongside major conservation programmes such as the KAZA TFCA in the hopes of fostering regional and economic growth (Kalvelage et al., 2021). Findings revealed that while corridors aim for broad economic growth, they often produce unintended challenges for local communities and businesses (Dannenberg et al., 2018; Kiesel et al., 2022). Local outcomes are strongly shaped by relationships between rural hinterlands, intermediate market towns, and neighbouring cross-border routes (Breul & Revilla Diez, 2021; Hulke & Revilla Diez, 2022). This dissertation adopts a mixed method approach to study the WBNLDC across multiple geographic levels. This dissertation examines how top-down corridor plans interact with local planning, conservation rules, and household livelihoods to shape regional development.

The dissertation uses four different data sources to analyse the developmental patterns along WBNLDC: satellite land use and cover data, satellite nighttime light data, primary household surveys, and official planning and policy documents. Each data source corresponds to a specific level of analysis in the study.

Paper 1 used satellite imagery in order to detect and classify changes in land use and cover along the WBNLDC. Mainstream planning theories and policy expectations suggest that transport corridors stimulate regional development by fostering the spatial agglomeration of economic activities (Schindler & Kanai, 2021). Therefore, there is an expectation to observe physical land use and cover changes on the ground through new business setups, settlement growth, and expanding agricultural fields; a pattern consistent with other frontier expansion (Barbier, 2012; S. Li, 2024). This study used agricultural cropland and built-up settlement areas as proxies for economic growth. This reflects the local population's heavy reliance on farming for their livelihoods and state development plans to transform the Zambezi Region into an agricultural "food hub" following the completion of the corridor. Analysing land use and landcover change (LULCC) also provides a concrete spatial estimation of how corridor investments may have driven development over time (Xiao et al., 2024). One major advantage of satellite datasets is their historical continuity, enabling a comparative pre- and post-analysis of the corridor's transformation. While tracking the main corridor highway is critical, paper 1 focuses on Zambezi Region to evaluate which types of road infrastructure are most conducive to changes in rural livelihoods. The paper uses cropland expansion and built-up area expansion as direct proxies for economic development and land use change because the rural population in the study area relies largely on agro-pastoralism (Kamwi et al., 2015). The underlying rationale is that both development corridors and regional/ rural roads are promoted to support agriculture and market access. Tracking how cropland and built-up classes have evolved across the region indicates whether rural households are expanding cultivated fields or whether new local enterprises and settlements are opening up along these transport routes. Establishing this local corridor transformation at a regional scale in the Zambezi Region establishes a clear historical timeline, paving the way for the larger cross-border analysis conducted in subsequent paper.

Paper 2 conducts a corridor-wide spatial analysis to track and explain the broader patterns of economic activity using satellite Night-Time Lights (NTL) time series data. Literature demonstrates that transport corridors do not automatically produce balanced spatial development; rather, they can lead to the formation of extractive enclaves (P. Carmody et al., 2022; Ferguson, 2006). Major transport corridors often function primarily as infrastructures of circulation, selectively linking high-value urban nodes, logistics hubs, and extraction sites to global markets while leaving intermediate rural hinterlands and peripheral regions bypassed (Schindler & Kanai, 2021; Scholvin, 2021; Zajontz, 2024). Using satellite-observed nighttime luminosity provides allows for cross-border analysis that overcome the limitations of fragmented and non-harmonised subnational administrative statistics across Namibia, Zambia, and the DRC (Storeygard, 2016). Crucially, the long-term availability of NTL datasets enables a time-series analysis covering pre-existing economic trends prior to major corridor infrastructure investments (Henderson et al., 2012). Assessing these pre-trend trajectories allows the study to test whether observed increases in economic activity were driven by the establishment of the development corridor itself or reflected pre-existing growth patterns already underway in specific urban and extractive nodes (Henderson et al., 2012). This macro-level approach connects the dissertation's overarching aim to contribute to the debate on whether transnational corridors foster neoclassical corridor-wide integration and agglomeration or reinforce selective integration and extractive enclaves.

Paper 3 analyses a quantitative panel household survey collected in the Zambezi Region across two waves in 2019 and 2023, to understand how proximity to various types of infrastructure influences household livelihoods outcomes and pathways. Literature often treats transport corridors as isolated interventions, assuming infrastructure lands in isolation independent of existing systems. However, major transport projects are built over established landscapes and interact directly with other regional strategies operating in the same territory (Kioko & Changwony, 2025). To capture these overlapping realities, paper 3 conceptualises the development corridors as part of an infrastructural assemblage. This assemblage is comprised of hard transport infrastructure such as the development corridor and regional roads (Schindler & Kanai, 2021), overlapping with soft infrastructure in the form of communal conservancies (Bollig & Krause, 2023; Hudalah, 2026). By

analysing household panel data across this assemblage, the paper explains how development corridors contribute to differentiated livelihoods outcomes. Rather than assuming physical road access automatically generates welfare gains, the analysis examines how infrastructure proximity interacts with other infrastructure and household capabilities to unlock different livelihood pathways (Dercon et al., 2009; Hulke et al., 2020). Uncovering who can actually leverage new infrastructure and who gets left behind is crucial as overlapping infrastructure represent an increasingly common logic across rural Sub-Saharan Africa.

As remote sensing captures spatial patterns rather than direct causality, all papers incorporated an analysis of policy and planning documents to account for endogeneity and identify co-occurring policy changes that could provide alternative explanations for the observed changes and patterns. This analysis covered national development plans (Vision 2030, NDP5), logistics strategies (Master Plan for Development of an International Logistics Hub for SADC Countries), regional trade plans (SADC) and many more (Japan International Cooperation Agency (JICA), 2015; Republic of Namibia, 2004, 2017; Southern African Development Community [SADC], 2012, 2020). Integrating these documents provides context on state planning goals and ensures that the empirical results are interpreted alongside agricultural and regional development plans.

3.3 Research Process and Sampling

The empirical findings of this dissertation were carried out in four different phases, from local field familiarisation to remote sensing. Each phase led to the publication of a research article. Data were collected in the Zambezi Region during the familiarisation phase in 2023. Table 2 provides an overview of the three individual research articles, detailing their respective study areas, guiding objectives, analytical methods, and publication status.

Table 2: Overview of research papers and guiding objectives

Study area	Guiding objective	Research article	Research methods	Publication status

Zambezi Region (Development corridors and regional roads)	To analyse patterns of development along the corridor and explain how uneven development emerges at regional level	Roads to development? A comparison of development corridors vs regional roads in the Zambezi Region, Namibia	Landsat (2000, 2004, 2015) & PlanetScope (2023) imagery, Google Earth Engine (GEE) LULCC classification, ground truthing and document analysis	Published in the Journal of Maps
The WBNLDC (Namibia, Zambia and DRC)	To analyse patterns of development along the corridor and explain how uneven development emerges at corridor scale	Development Corridors in Southern Africa: Navigating Unfulfilled Visions and Complex Realities	Harmonised DMSP-OLS & VIIRS-DNB NTL time series (1992–2024), Difference-in-Differences (DiD), Propensity Score Matching (PSM) and	Under Review at the European Journal of Development Research

			document analysis	
Zambezi Region (Development Corridor, Regional Roads and Communal Conservancies)	To examine how household proximity to an infrastructural assemblage (corridor, regional roads, and communal conservancies) shapes rural livelihood outcomes and pathways	Infrastructural Assemblages and Uneven Livelihoods: Roads, Corridors and Conservancies in Rural Namibia	Household panel survey (2019 & 2023), proximity measures and document analysis	Submitted for publication at the World Development Journal

Phase 1: Exploration & Familiarisation (Jan–Jul 2023)

I started my PhD work in Cologne in December 2022 within the CRC TRR 228 project (C01 Future in Chains). My first step was to review what project members had published during phase I to identify gaps and determine which methods to use. I selected remote sensing and Geographic Information System (GIS) as a practical starting point. After completing a training session on using high resolution PlanetScope imagery, I created a preliminary land classification map. I went on a one-month field trip to the Zambezi Region to familiarise myself with the study area. Working with local field assistants, I collected more than 600 GPS ground points to build and verify land cover classes. I also met with regional stakeholders, including the Ministry of Agriculture, Fisheries, Water and Land Reform, the Zambezi Regional Council in Katima Mulilo, local headmen, and Traditional Authorities (Khutas) to gain a local understanding of the study area. This phase was necessary for the next phases.

Phase 2: Satellite Image Processing and Land Use Analysis

Once I returned back to Cologne, I obtained high resolution satellite datasets in order to analyse the land use and cover changes over time. I selected the following four period for analysis: 2000 (representing the tarring of the Trans-Caprivi Highway), 2004 (after the completion of the Katima Mulilo bridge and cross-border corridor), 2015 (after the tarring of regional roads), and 2023 (current status). These images were analysed and processed in GEE and ArcGIS Pro. Final analysis were carried out within 10 km buffers along the corridor and regional roads, as well at roads intersection in Kongola, Liselo, and Katima Mulilo. Combining spatial change detection with policy document analysis to account for alternative policy driver resulted in paper 1 as shown in Table 2.

Phase 3: Cross-Border NTL Analysis

In the next phase I expanded the study area to cover the entire corridor through Namibia, Zambia, and the DRC. I conducted a desktop review of the major economic sectors along the route (mining, agriculture, and tourism) and obtained harmonized time series DMSP-OLS and VIIRS NTL data (1992–2024) from PCNL. I used a DiD method to compare light growth within 25 km of the corridor against hinterland areas (30 km to 110 km away). In order to address issues of endogeneity and selection bias, I employed the propensity score matching (PSM) method to pair treated cells with control cells that showed similar initial characteristics. In addition, an attempt to review the global commodity booms and rural electricity grids was done to ensure there was no misidentification of power line expansion or mining surges as indicators of corridor-driven growth. This macro-level analysis allowed for a deeper understanding of economic activity patterns across the whole corridor. I created an analytical framework that characterise the patterns observed into either neoclassical corridor wider integration or the critical economy persecutive of selective integration and extractive enclaves. This research has resulted in paper 2, which is currently under peer review at the European Journal of Development Research.

Phase 4: Household Panel Analysis

The second study revealed that the economic growth experienced along the corridor was uneven. In Phase 4 of the study, the aim was to understand the implications of the findings for local communities. The Zambezi Region was revisited as a case study, with the focus being on how households interact with a landscape comprising corridors, regional roads and communal conservancies. The study used the CRC household survey dataset, collected in the Zambezi Region in 2019 and 2023. A GIS network model was developed to calculate the shortest travel time from each household to the nearest district road, main road, or corridor. Using these travel times alongside the household survey variables, I ran regression models to test the association between proximity to infrastructure and different livelihood outcomes. I also evaluated the trade-offs of living in conservancies, close to roads and how this shapes livelihood outcomes and pathways. This completed paper 3, which is submitted for publication at the World Development journal.

3.4 Data Analysis and Triangulation

The datasets used in this study were analysed quantitatively using various methods, which are listed in Table 3 and in the specific papers in the next section. A combination of spatial statistics, econometrics and policy analysis was used.

Table 3: Data Analysis Techniques

Article	Analysis
Roads to development? A comparison of development corridors vs regional roads in the Zambezi Region, Namibia	Quantitative: Satellite imagery (Landsat 5, 7, 8, and PlanetScope) for 2000, 2004, 2015, and 2023 was processed in GEE and Esri ArcGIS Pro. Policy analysis: National Development plans, Newspaper news articles, logistics master plans

Development Corridors in Southern Africa: Navigating Unfulfilled Visions and Complex Realities	Quantitative: Pixel-scale Corrected Nighttime Light Dataset (1992–2024) along the WBNLDC using a DiD framework paired with PSM. Policy analysis: National Development plans, logistics master plans, newspaper articles, commodity boom cycles
Infrastructural Assemblages and Uneven Livelihoods: Roads, Corridors and Conservancies in Rural Namibia	Quantitative: Household panel survey data from 2019 and 2023 were linked to a GIS network model that calculated the shortest travel time from each household to the road network

Adopting a mixed methods approach across multiple geographic scales allows for data triangulation and improves the reliability of the empirical findings while reducing biases inherent of any single data source (Fielding, 2012). To draw meaningful conclusions regarding the developmental outcomes of the Walvis Bay Ndola Lubumbashi Development Corridor (WBNLDC), this dissertation employs a cross-validation approach, using data from remote sensing imagery, NTL time series, household panel surveys and policy document analysis across transnational, subnational and local scales. Each dataset used in this study compensates for the specific analytical limitations of the others. For example, while multi-temporal satellite imagery provides a historical spatial perspective at regional level that would be impossible to capture through household surveys alone, household panel surveys add the local level data needed to explain the specific livelihood outcomes. Given the inability of satellite remote sensing to establish direct causality among co-occurring processes, policy documents were deemed necessary to provide the institutional context required to explain observed patterns and account for alternative policy interventions. An analysis of spatial patterns within the Zambezi Region alone cannot be generalised to the entire transnational corridor, just as

corridor level patterns cannot be used to capture localised realities. Multi-scalar analysis is therefore essential for achieving a balanced, empirically grounded synthesis.

3.5 Reflection of the Research Design

Critical reflection on the research design is an essential part of the dissertation process, providing context for the findings and acknowledging the practical boundaries of method as well as the reliability and limitations of the research findings. Although the multi-scalar mixed methods framework used in this dissertation provides a rich foundation for analysing developmental outcomes, there are several key trade-offs and technical limitations require careful consideration.

Firstly, the use of land use and land cover change (LULCC) as a proxy for development provides an objective measure of land expansion. However, this approach does not reveal who benefits from the expansion or reflect household level earnings and socioeconomic well-being. This was partially addressed by integrating micro-level household panel surveys in paper 3. However, it should be complemented with additional data to represent livelihood or development. Second, a comparison of regional roads with development corridors may introduce bias in the analysis, given that each possesses a distinct scope. Asher et al. (2018) and Kunaka & Carruthers (2014) posit that development corridors are geared towards broader economic impacts, whereas regional roads serve local needs (Asher et al., 2018; Kunaka & Carruthers, 2014). Therefore, the results of this study in this regard are only a beginning base for further studies in related matters.

Third, the NTL datasets utilised in this study are known to possess certain limitations, particularly when combining long-term data from DMSP-OLS and VIIRS sensors, which necessitate harmonization (Elvidge et al., 2001). Despite the existence of various harmonized NTL products, fewer of these cover the global scale. Of those that do, some trade-offs have been identified (S. Li et al., 2023; X. Li et al., 2020). PCNL was selected as the optimal solution was determined through a comprehensive evaluation of multiple products, which revealed its superiority in addressing saturation, flaring, and blooming issues when compared to alternative solutions (S. Li et al., 2023). However, NTL only picks up economic activities tied to the electricity grid. In Sub-Saharan Africa, particularly in

rural areas with low baseline luminosity, off-grid economic activities are excluded from satellite detection (Gibson et al., 2021). However, because development corridors are expected to attract investments including electrification, a lack of electricity along a corridor reflects a delay in corridor-driven development, even if it leads to informal economic activities that NTL cannot capture. Conversely, intense luminosity in open-cast mining areas along the corridor makes it difficult to separate the effects of mineral extraction from those of infrastructure development.

Fourth, the household data are based on two survey waves that depend on household recall for annual expenditures and farm earnings. Recall errors is a recognised issue in rural surveys, especially where formal record keeping is limited (Beegle et al., 2012). Using travel distance as a proximity proxy also presents a challenge. Many households lack the capabilities to use roads for livelihood improvements. This limitation was partly addressed by including survey questions on household vehicle ownership however access still depend on capabilities that distance alone does not capture.

Finally, infrastructure placement is rarely random. In the planning process, routes are selected by planners based on pre-existing economic potential, political interests, and resource availability (Bansal, 2025; Redding & Turner, 2015). This means that observed growth along a route may reflect expected outcomes that were already underway. In light of this, the present study has chosen to present its results as spatial associations rather than making direct causal claims. The present study utilised PSM matching and policy document reviews in order to account for any potential alternative explanations and thereby provide an institutional context for the observed patterns. Overall, the findings should be interpreted with these limitations in mind. They provide robust evidence of spatial patterns and associations, but uncertainty remains around causality, off-grid activity and the full distribution of benefits.

4. Roads to development? A comparison of development corridors vs regional roads in the Zambezi Region, Namibia

Source: Justina Tuulikefo Nangolo, Christoph Hütt, Georg Bareth & Javier Revilla Diez (2025) Roads to development? A comparison of development corridors vs regional roads in the Zambezi Region, Namibia, *Journal of Maps*, 21:1, 2462302, DOI:10.1080/17445647.2025.2462302

Abstract

Despite the increasing popularity of development corridors, doubts have been raised about their promised outcomes concerning the promotion of regional development, especially when compared to fostering regional roads instead. As the impacts of different types of roads on land use changes remain inadequately understood, this study utilised Landsat and Planet scope satellite imagery to compare land use transformation along the *Walvis Bay - Ndola - Lubumbashi Development Corridor (WBNLDC)* and regional roads in the Zambezi Region, Namibia. A random forest supervised classification model was used to characterise land use change within a 10km corridor effect zone along the development corridor and regional roads in the Zambezi Region. Overall, the Zambezi Region experienced a strong increase in built-up areas (+236%) and cultivated land (+69%) between 2000 and 2023 at the expense of forest (-15%) and grasslands (-15%). Cultivated land and built-up areas consistently expanded along all roads, but most intensively along the regional roads where the majority of the inhabitants live rather than the *WBNLDC*. Interestingly, most of this expansion was observed after the tarring of regional roads, highlighting their role in driving land use change in the study area. The expansion of cultivated land and built-up area along regional roads suggest that local communities profit more from regional roads, and targeted investment in regional roads rather than international corridors like *WBNLDC* might be beneficial to achieving the region's food basket goals and thus improving their livelihoods.

Keywords:

Land use change, development corridors, regional roads, cultivated land, built-up area, livelihoods

Key Policy Highlights

- The research uses the expansion of cultivated land and built-up areas along development corridors and regional roads as proxies for rural development, highlighting the economic significance of agriculture for rural communities' livelihoods.
- Observed land use changes suggest that infrastructure development, mainly through regional roads, can potentially improve rural livelihoods by linking built-up area and cultivated land expansion to broader economic opportunities.
- The study emphasises the need for policies that strengthen rural connectivity, promote inclusive development, and maximise the benefits for local communities.

4.1 Introduction

In recent years, development corridors have emerged as promising drivers of economic development, particularly in peripheral regions like Sub-Saharan Africa. Development corridors are regional strategies meant to integrate places and foster development (Mulenga, 2013). These corridors, often in the form of highways, are envisioned as pathways that connect various regions to global markets, facilitating the efficient movement of goods and services, and fostering economic growth (Priemus & Zonneveld, 2003; Hope & Cox, 2015).

Previous research has shown that understanding the dynamics of land use change is crucial for comprehensively assessing the outcomes of development corridors (Zheng et al., 2021; Sang et al., 2022). The effect of development corridors on land use patterns, both direct and indirect, leads to significant transformations in landscapes and human activities (Sang et al., 2022; Van Der Ree et al., 2015). In recent years, doubts have been raised whether the outcomes of these corridors truly align with the anticipated outcomes, which include benefiting the locals (Witte, 2014; Enns, 2018). It is expected that a more affordable access to markets will reduce transport cost, promote job creation and improve livelihoods. However, development corridors are reported to pose social and environmental challenges, including uneven developmental impacts, marginalising the poor, threatening biodiversity and vulnerability to the impacts of climate change (Byiers et al., 2016).

Launched in 1999 with the opening of the Trans-Caprivi Highway, the *WBNLDC* is a crucial transportation link connecting the Walvis Bay port to Zambia and the Democratic Republic of Congo. This corridor supports Vision 2030 and Namibia's National Development Plans (NDPs), which collectively call for infrastructure development, employment creation and improved income equality (Republic of Namibia, 2021). In respect to the Zambezi Region, the corridor development plan foresees a stimulation of economic activities through agricultural intensification, manufacturing, tourism, and logistics (Aurecon, 2014). To sum it up, the purpose of the *WBNLDC* is not only focusing on central nodes along the corridor like Walvis Bay or Katima Mulilo, but it also purposively aims to unlock the economic potential in the rural areas in between (Ndjavela, 2021; Southern African Development Community [SADC], 2007).

Previous studies in the Zambezi Region demonstrate that the region has witnessed a noticeable increase in tourism and conservation activities since then (Gronau et al., 2017; Zeller, 2009), but more recent studies have indicated that some of the anticipated benefits of the corridor have not yet materialised, neither in tourism nor in agriculture (Ratz, 2021; Hulke et al., 2020; Kalvelage et al., 2021). This raises questions about the developmental impacts of the *WBNLDC* in the Zambezi Region and more generally, whether development corridors are really conducive to achieving inclusive development, directly benefiting local communities. Consequently, there is an ongoing call to prioritise regional road infrastructure instead (Kingombe, 2011; Titheridge, 2014; Dannenberg & Revilla Diez, 2018). However, there is a lack of studies comparing the impact of development corridors vis a vis regional roads.

Using Zambezi Region as a case study, this study aims to compare land use changes along the *WBNLDC* and regional roads in the Zambezi Region using GIS and RS to provide a first assessment of the developmental impact of development corridors compared to regional roads. The expansion of cultivated land, which is the most prominent livelihood strategy in the Zambezi Region (Colpaert et al., 2013) and the expansion of the built-up area are used as a proxy for improved economic opportunities for small-scale farmers. This clearly links our study to the United Nations's Sustainable Development Goals (SDGs), which call for sustainable infrastructures and building inclusive communities (SDG 2, 11, and 15) (United Nations, 2015) and is, to our knowledge, the first study doing it for the Zambezi Region.

The study employs a methodology adapted from Rufin et al., 2022, to deliver a novel contribution and valuable insights into the interactions of development corridors, regional roads, and land use patterns. This study offers policymakers valuable information on changes and policy reforms to prioritise strategies that truly benefit regional development. It also supports SDGs and the country 's NDPs through evidence-based planning.

4.2 Materials and Methods

4.2.1 Study Area

The study is centred on the Zambezi Region (Figure 2) in northeastern Namibia, covering 14 530 km², more than half of which is under conservation. This region is characterised by subsistence agriculture and has faced high unemployment (48 % in 2016) and poverty rates (54 % in 2021) (Namibia Statistics Agency, 2017; 2021; Colpaert et al., 2013). Infrastructural projects such as the *WBNLDC* in 1999 and the Zambezi River Bridge to Zambia in 2004 were introduced to not only connect the seaport of Walvis Bay to Zambia and the Democratic Republic of Congo, but also to connect and bring the Zambezi Region closer to the rest of Namibia (SADC, 2007) through improved connectivity (Zeller, 2009). This was followed by the tarring of regional roads in the Zambezi Region as part of the larger infrastructural development in the region, which was completed in 2014 (New Era, 2014). The analysis focuses on the impact of the *WBNLDC* compared to regional roads, particularly regional road 1 (Linyanti – M0125) and regional road 2 (Ngoma – T 807). The Zambezi Region has been identified as having the potential to become a key contributor to Namibia's food security, often referred to as the nation's 'breadbasket'; and having agricultural growth is one of its main developmental visions (Kiesel et al., 2022). This study analysed changes in land use, focusing on cultivated land and built-up areas along roads, as these indicators directly reflect the region's development trajectory, particularly given its dependence on agriculture for their livelihoods. The expansion of cultivated land is interpreted as the expansion of agricultural production improving the livelihoods of the local population and food security (Kuang et al., 2022). The increase in built-up areas stands for the expansion of settlements, which represent market and job opportunities and the provision of public infrastructure like schools and medical centres and is used as another proxy for improved livelihood conditions (FAO et al., 2023).

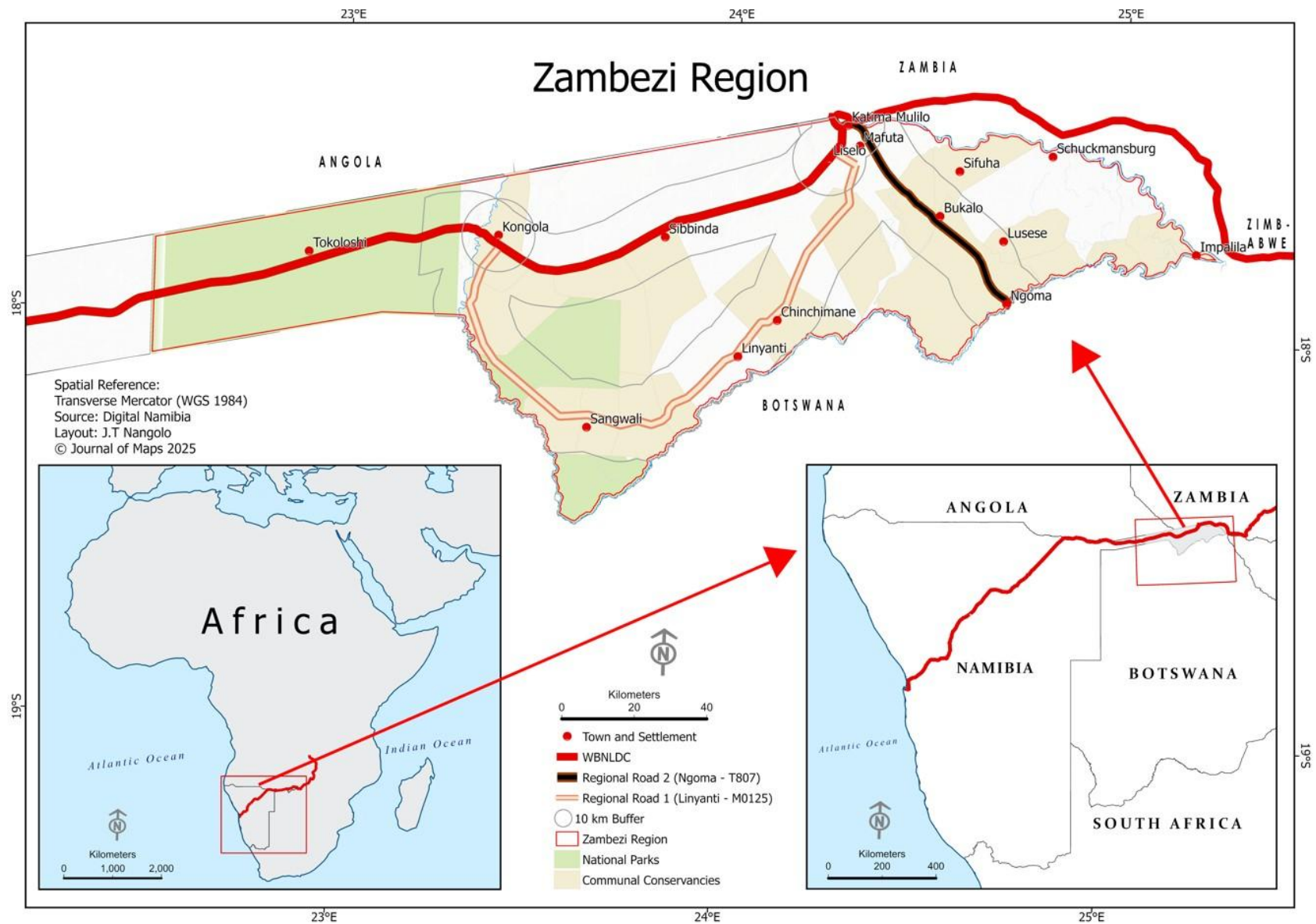


Figure 2: Map of Zambezi Region. Source: Author's own design

4.2.2 Mapping Land Use Change

Landsat 5 TM; Landsat 7 ETM+, Landsat 8 OLI, Planet scope daily scenes and monthly base map images for Africa provided by the Norwegian International Climate and Forest Initiative (NICFI) project were primarily used to classify land use changes in the study area for the year 2000, 2004, 2015, and 2023. The 2000 images marked the *WBNLDC*'s inauguration, while the 2004 images marked the *WBNLDC*'s completion to Zambia and DRC. Images from 2015 represented the tarring of regional roads as an important milestone for the region. Planet scope images for 2023 were included to create a complete time series for analysing the land use change along the *WBNLDC* and regional roads in the Zambezi Region. Data processing was done using Google Earth Engine (GEE) due to its high computational capabilities and ability to handle large datasets. Following examples from the literature (Li et al., 2022; Sang et al., 2022), a corridor effect zone extending 10 km on either side of these roads was established, with separate buffers around the settlements and towns of Kongola, Liselo, and Katima Mulilo where the regional roads intersect the *WBNLDC*. In this study, the areas around the Katima Mulilo and Liselo intersections are combined and referred to as "Katima" because they are close and overlap.

Data Preprocessing

The analysis was carried out following a methodology adapted from Rufin et al. (2022). First, we searched the GEE database for all the images captured during our years of analysis. A total of 30 Landsat 7 images for 2000, 52 Landsat 5 images for 2004, 130 Landsat 8 images for 2015, and 13 planet scopes for 2023 scenes were used for the analyses. Each year of analysis was processed separately following similar steps (Figure 3) to allow for time series comparisons.

Images went through image processing to prepare them for analysis such as data cleaning, conversion to spectral reflectance and calculation of the Normalised Difference Vegetation Index (NDVI) (Equation 1), as well as computation of spectral temporal metrics (Goodwin et al., 2012; Rouse et al., 1973). For each year of analysis, we calculated the median, standard deviation, 25th percentile, 75th percentile, and interquartile range for the Green, Blue, Red, Nir, and NDVI bands (Xiong et al., 2017; Rufin et al., 2022). In order to identify agricultural land patterns, which are normally challenging in small-scale agricultural systems, we calculated the texture and contrast index based on the NDVI at various radii (Rufin et al., 2022; Xiong et al., 2017). We added auxiliary data on agriculture and built-up areas from existing sources (Reichelt-Zoho et al., 2022) to the statistical metrics to aid with image classification for 2015 and 2023. Temporal metrics, texture, contrast index, and auxiliary data were stacked together and sub-set into smaller tiles for image classification.

The formula for NDVI is as follows:

$$1) \text{ NDVI} = \frac{\text{Nir} - \text{Red}}{\text{Nir} + \text{Red}}$$

where: NDVI is the Normalised Difference Vegetation Index, NIR is the Near Infrared band, and Red is the Red band.

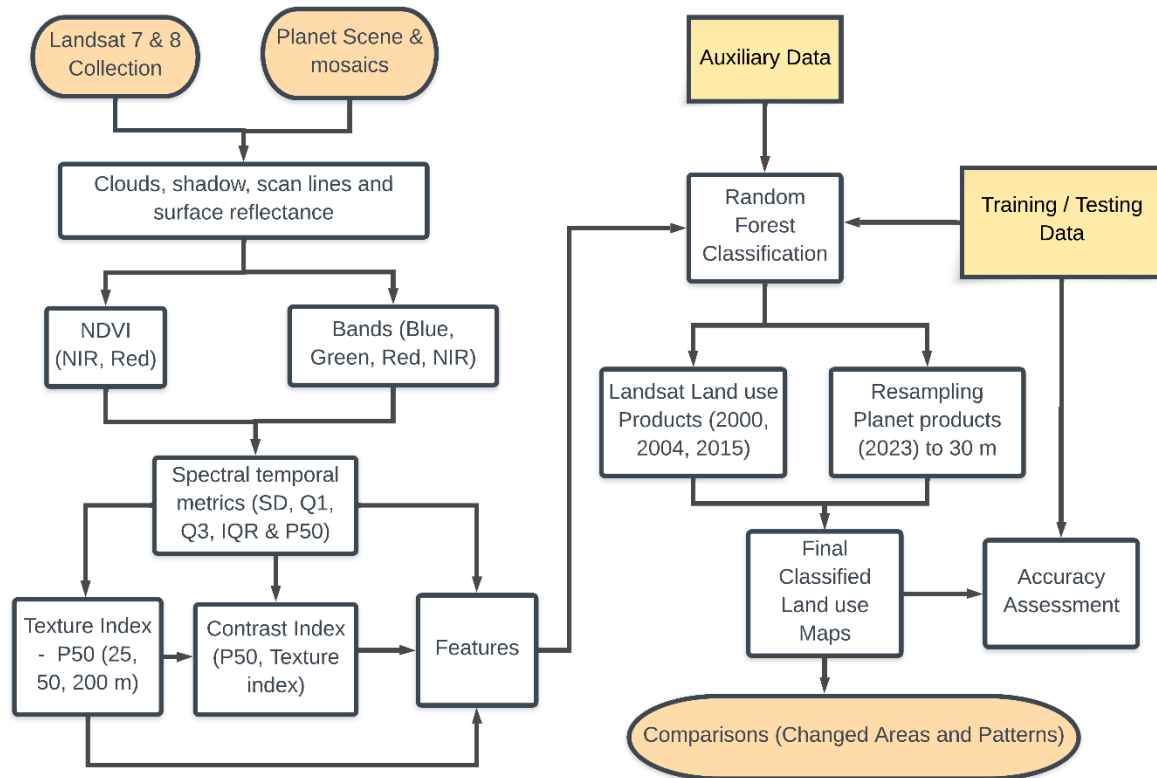


Figure 3: Workflow Diagram. Source: Authors's own design. NB: Q1 (25th percentile), P50 (Median, 50th percentile), Q3 (75th percentile), IQR (Q3 - Q1), and SD (Standard Deviation)

Ground Truthing

To evaluate image classification accuracy, 759 randomly distributed ground control points were collected from the field in June and July 2023. These points are essential for measuring how accurately pixels are classified into the correct land cover category (Rwanga & Ndambuki, 2017; Sang et al., 2022). In this study, a confusion matrix (Lewis & Brown, 2010) was created and used to calculate the overall accuracy and the F1-score which was used as a measure of accuracy. The overall accuracy represents the percentage of correctly classified points, while the F1-score provides deeper insights into the effectiveness of the classifiers across individual classes and beyond the overall accuracy (Muntean & Militaru, 2023).

Land Use Classification and Change Analysis

A random forest supervised classification approach was utilised to classify the study area into six land use classes, including built-up, cultivated land, waterbody, forest, grassland, and wetland (Breiman, 2001; Rufin et al., 2022). Firstly, an independent training dataset was created using the knowledge of the study area, visual interpretation, and Google Earth. Secondly, for the first three years of our analysis, the training dataset was split into 90% for model training and 10% for testing accuracy. In the last year of analysis, the entire training dataset was used to train the model, and its accuracy was tested using the in situ ground truth data. Due to the size of the study area, a classifier was first trained based on the model training data. This classifier was later used to classify individual tiles making up the entire study area. Finally, the classified tiles were combined for further analysis.

Post-classification change detection was employed to create a land use transfer matrix, which illustrates the movement of land use across different categories over time. To measure the magnitude and rate of changes in land use categories, both rate of change, single and dynamic land use dynamic degree indices were calculated (Equations 2, 3, 4). These indices provide a quantitative assessment of the extent and speed of land use change over the study period as well as the overall land use dynamics across multiple intervals and land use categories. The following table presents the equations used to calculate these measures in the study (Xiao et al., 2024, Sarfo et al., 2024):

- 2) *Rate of change (%)* = $\frac{A_2 - A_1}{A_1} * 100$, where A_1 is the area at the start of a study period, and A_2 is the area at the end of the study period
- 3) *Single Dynamic Degree of Change* $\frac{A_2 - A_1}{A_1} * \frac{1}{T} * 100$; where T is the study duration
- 4) *Comprehensive Dynamic Degree of Change* $\frac{\sum(U_{ij} + U_{ji})}{A_{total} * T} * 100$ where U_{ij} is the area of land use type i converted to type j , and U_{ji} is the area of land use type j converted to type i .

4.3 Results

4.3.1 Accuracy Assessment

Based on the confusion matrixes, table 1 (Table 4) reveals that the overall accuracy for all years of classification is above 80 %. This indicates a substantial and almost perfect agreement between the classification and the testing data (Rwanga & Ndambuki, 2017; Sang et al., 2022), making the classification reliable.

The F-score (Table 4) indicated that classes such as forest, cultivated land, and built-up land performed exceptionally well, while grassland and wetlands suggested that the model had trouble classifying these classes.

Table 4: Classification Accuracy for all years of classification and F1 score for the 2023 results. Source: Authors' own design

Land use class	2023 F-score (F1)
Waterbody	0.70
Cultivated land	0.93
Built-up	0.92
Forest	0.89
Wetland	0
Grassland	0.4
Overall accuracy 2023	80 %
Overall accuracy 2015	86 %
Overall accuracy 2004	85 %
Overall accuracy 2000	88

4.3.2 Land Use Change

Land use changes were evident along roads in the Zambezi Region from 2000 to 2023 (Figure 4, 5). Forests remained the dominant land use throughout the study period, covering more than 40 % of the area within 10 km of the roads analysed. In 2000, grassland was the second most dominant land use after forest. However, by 2023, cultivated land had become the second-largest category, accounting for about 24 % of the area—an increase of 14 % since 2000. Both forests and grasslands saw significant decreases by 2023, while cultivated land and built-up areas showed notable growth. Spatially, cultivated land and built-up areas were most prominent along roads and near major towns and settlements, including Katima Mulilo, Bukalo, Ngoma, Linyanti, Sagwali, Kongola, and Sibbinda. Although all roads experienced an upward trend in cropland, the most changes were found at Linyanti between 2000 and 2023. Meanwhile the Ngoma Road experienced the most significant increase in built-up area.

The temporal analysis (Figure 4 A) shows an upward trend in cultivated land and built-up area during the first years of analysis after the opening of the Trans-Caprivi Highway in 2000, which continued for the next eleven years after the completion of the Zambezi bridge, albeit at a very slow pace (Table 5). After 2015, coinciding with the

tarring of regional roads in 2014, the rate of expansion for built-up area and cropland increased sharply.

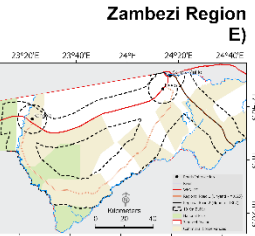
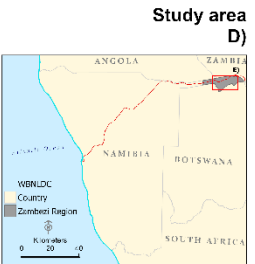
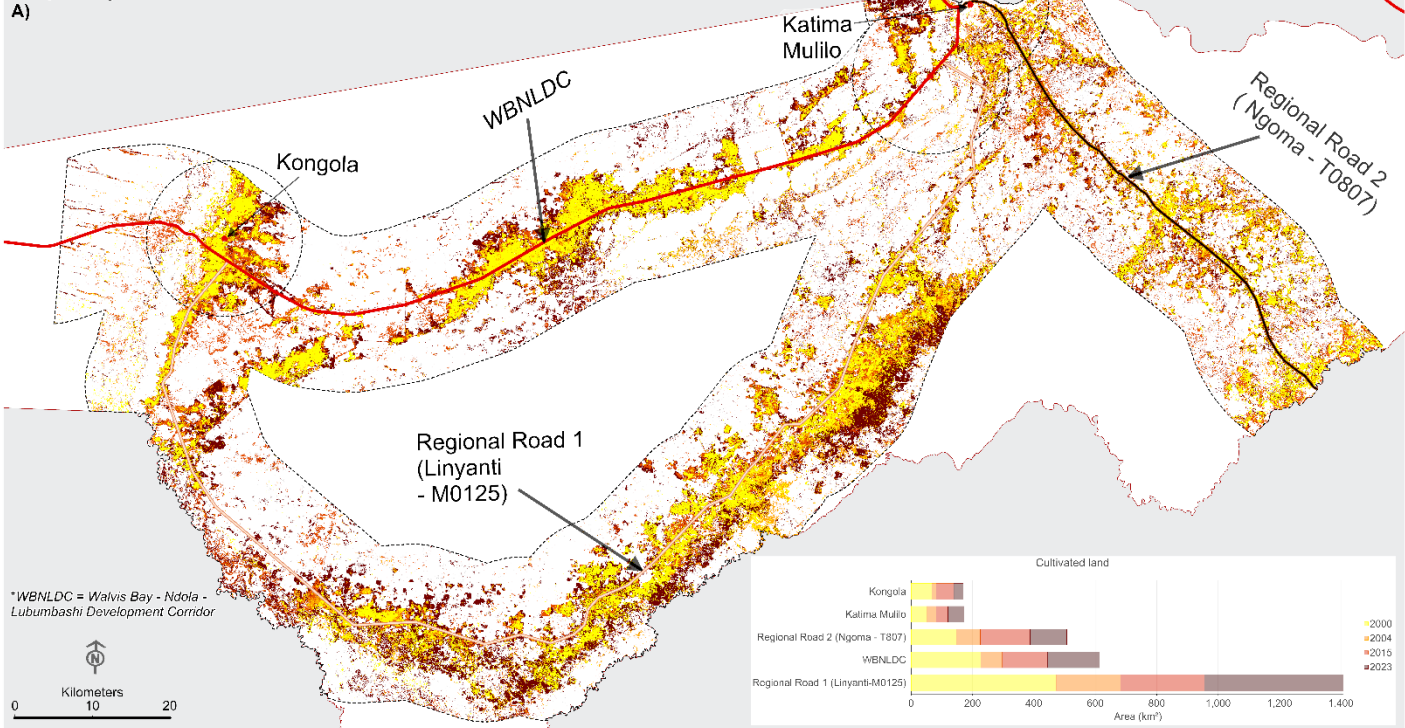
An analysis of road types and development strategies revealed notable differences (Figure 4, Table 6 & 7). The Linyanti Road experienced the most significant expansion of cultivated land, with the majority of the increase (420.0 km²) occurring after its tarring (420 km²), compared to 26 km² before the corridor's completion and only 75 km² after the corridor's completion. The *WBNLDC* also showed an upward trend in cultivated land, but the increase was comparatively smaller, with 30 km² before and 74 km² after the corridor's completion. For built-up areas, the Ngoma Road saw the largest expansion, mirroring the trend observed for cultivated land, with the most growth occurring after the tarring of regional roads. Both the Linyanti Road and the *WBNLDC* experienced similar increases in built-up areas. At road intersections, built-up area expansion was also much higher after the tarring of regional roads, with Katima Mulilo leading in built-up area growth, while Kongola recorded the largest increase in cultivated land.

From 2000 to 2004, the single dynamic degree of change (Figure 5) revealed that cultivated land had the highest expansion along *WBNLDC* (3.7%), followed by LinyantiNgoma (2.14%), while *Ngoma* (2.1%) had the lowest. However, after the completion and opening of the Zambezi Bridge (2004–2015), the results reveal a significant reductions in dynamic changes across all roads except *Ngoma*. In the final period (2015–2023), following the tarring of regional roads, the dynamics of cultivated land and built-up areas surged significantly. Linyanti regained its dominance in cultivated land expansion with a dynamic degree above 10%, similarly *Ngoma* showed substantial growth in built-up areas, leading with a dynamic change degree of 15.9%. A similar trend can be observed using the comprehensive dynamic degree of change (Figure 6). The Linyati road had the highest dynamic degree of land use change at the start of the analysis. However, a decline in changes was observed for all roads, with *WBNLDC* having the lowest changes. The last period of analysis (2015–2023) shows that the indices slightly increased, with Linyanti taking the lead and increasing above 5%%.

Roads to development? A comparison of development corridors vs regional roads in the Zambezi Region, Namibia

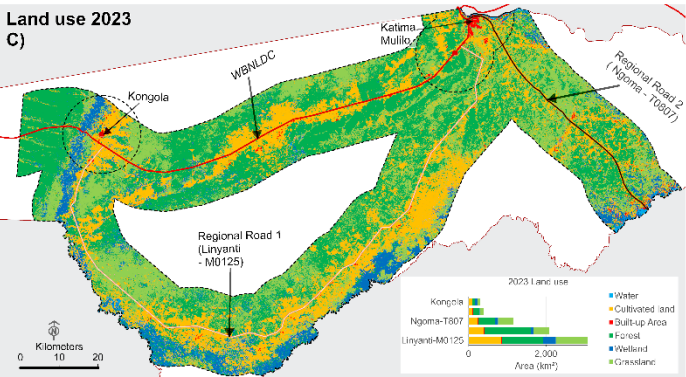
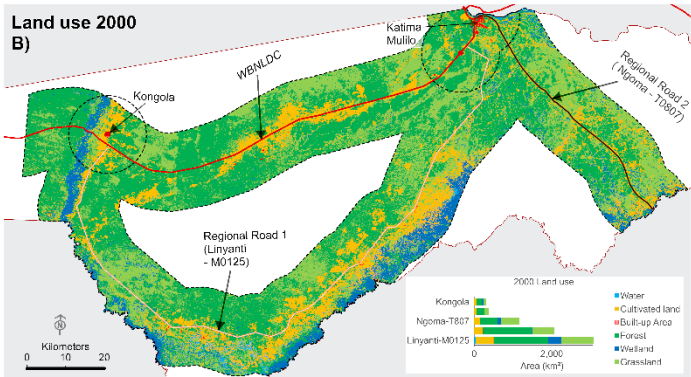
J.T. Nangolo, C. Hütt, G. Bareth, J. Revilla Diez, Institute of Geography, University of Cologne

Temporal dynamics of cultivated land



Spatial Reference:
Transverse Mercator (WGS 1984)

Source: Author's compilation
Layout: J.T. Nangolo, R. Spahnner
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The map design illustrates land use changes along the Walvis Bay - Ndola - Lubumbashi Development Corridor (WBNLDC) and regional roads in the Zambezi Region, focusing on areas within a 10km buffer from the roads. The study uses cultivated land and Built-up area as indicators of development, focusing on its evolution along these roads. The main map (A) displays the expansion of cultivated land along each road and their intersections at Katima Mulilo and Kongola over the four years of analysis. The additional maps show land use in 2000 (B) and 2023 (C) indicating the changes in land use over 23 years. For context, an inset map (D) shows the location of the study region and the WBNLDC, while another inset map (E) zooms in to detail the regional roads, WBNLDC, and the intersections.

Figure 4: Land use change dynamics along the WBNLDC and regional roads in the Zambezi Region from 2000 to 2023. Source: Authors' own design

Table 5: Overall land use change within the 10km buffer of all roads in the Zambezi Region. Source: Authors' own design

Land use								
Land use class	2000		2004		2015		2023	
	km²	%	km²	%	km²	%	km²	%
Waterbody	60.7	0.9	49.5	0.8	18.4	0.3	32.0	0.5
Cultivated land	675.1	10.3	735.9	11.2	1018.3	15.5	1595.8	24.3
Built-up	30.4	0.5	51.2	0.8	60.0	0.9	80.8	1.2
Forest	3354.5	51.0	3118.7	47.5	2910.3	44.3	2728.4	41.5
Wetland	475.9	7.2	542.0	8.2	588.4	9.0	529.6	8.1
Grassland	1975.6	30.1	2075.0	31.6	1976.9	30.1	1604.9	24.4
Total	6572	100	6572	100	6572	100	6572	100

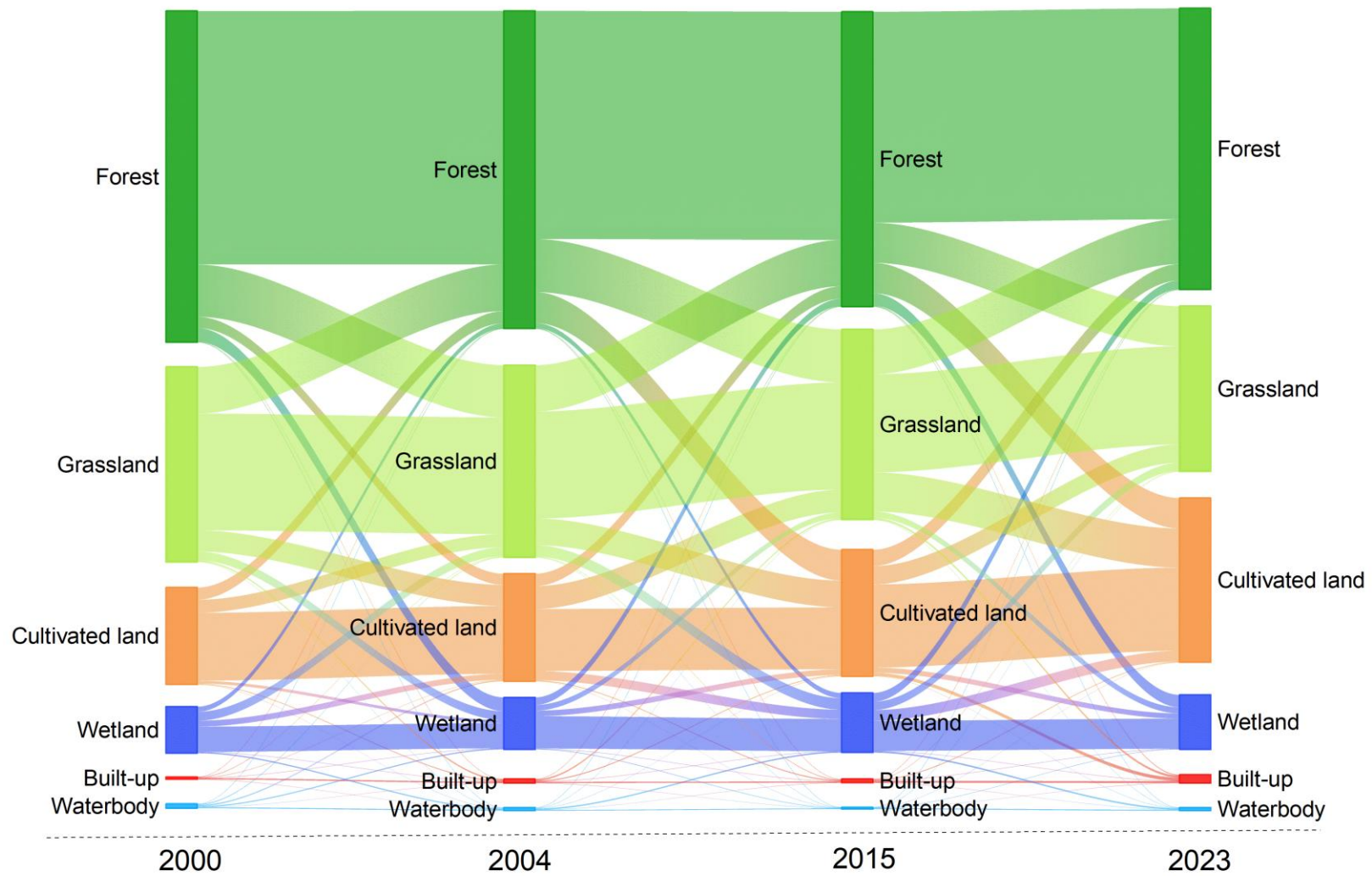


Figure 5: Land use changes along 10km of roads in the Zambezi Region. Source: Authors' own design

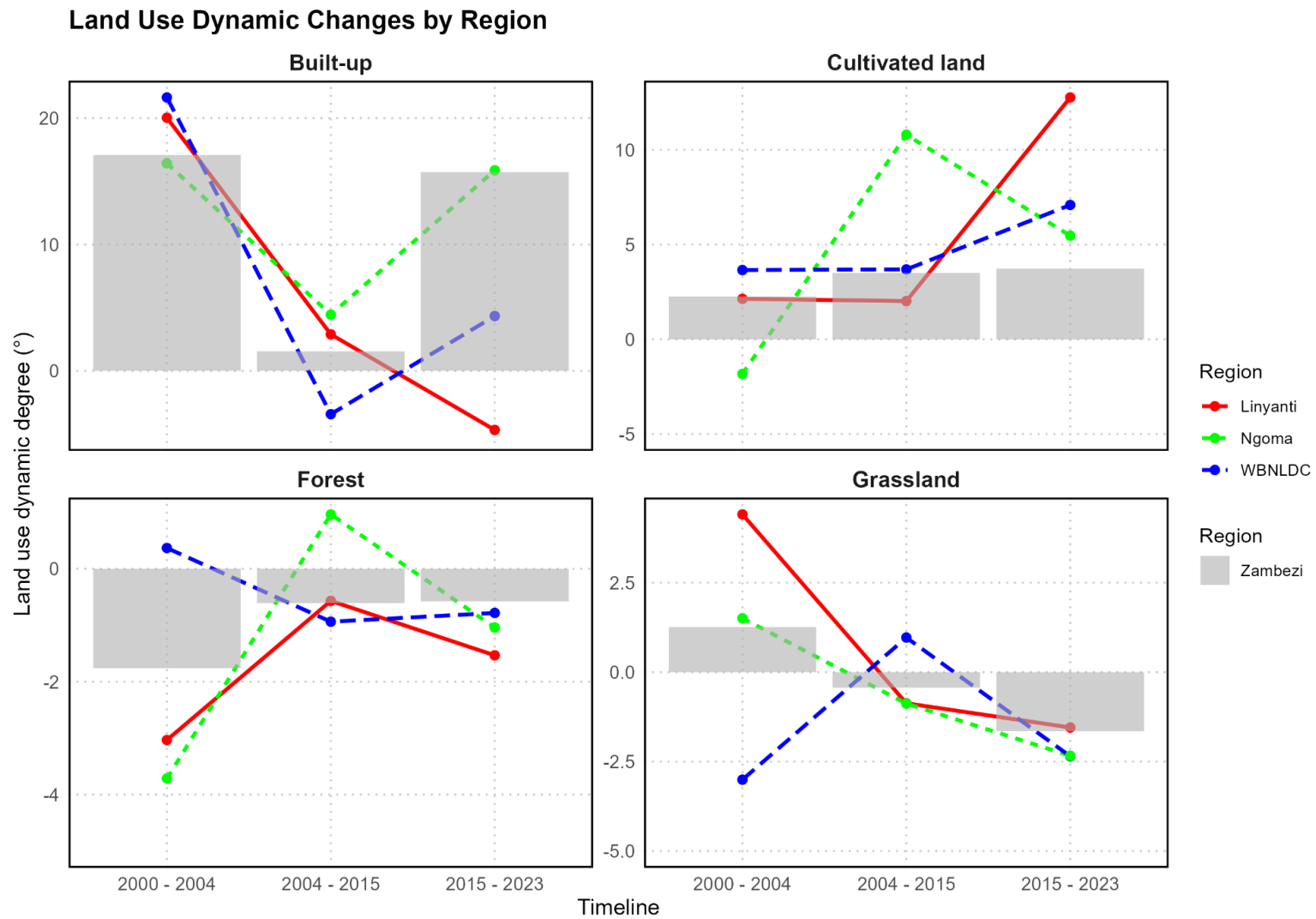


Figure 6: Single land use dynamic degree. Source: Authors' own design

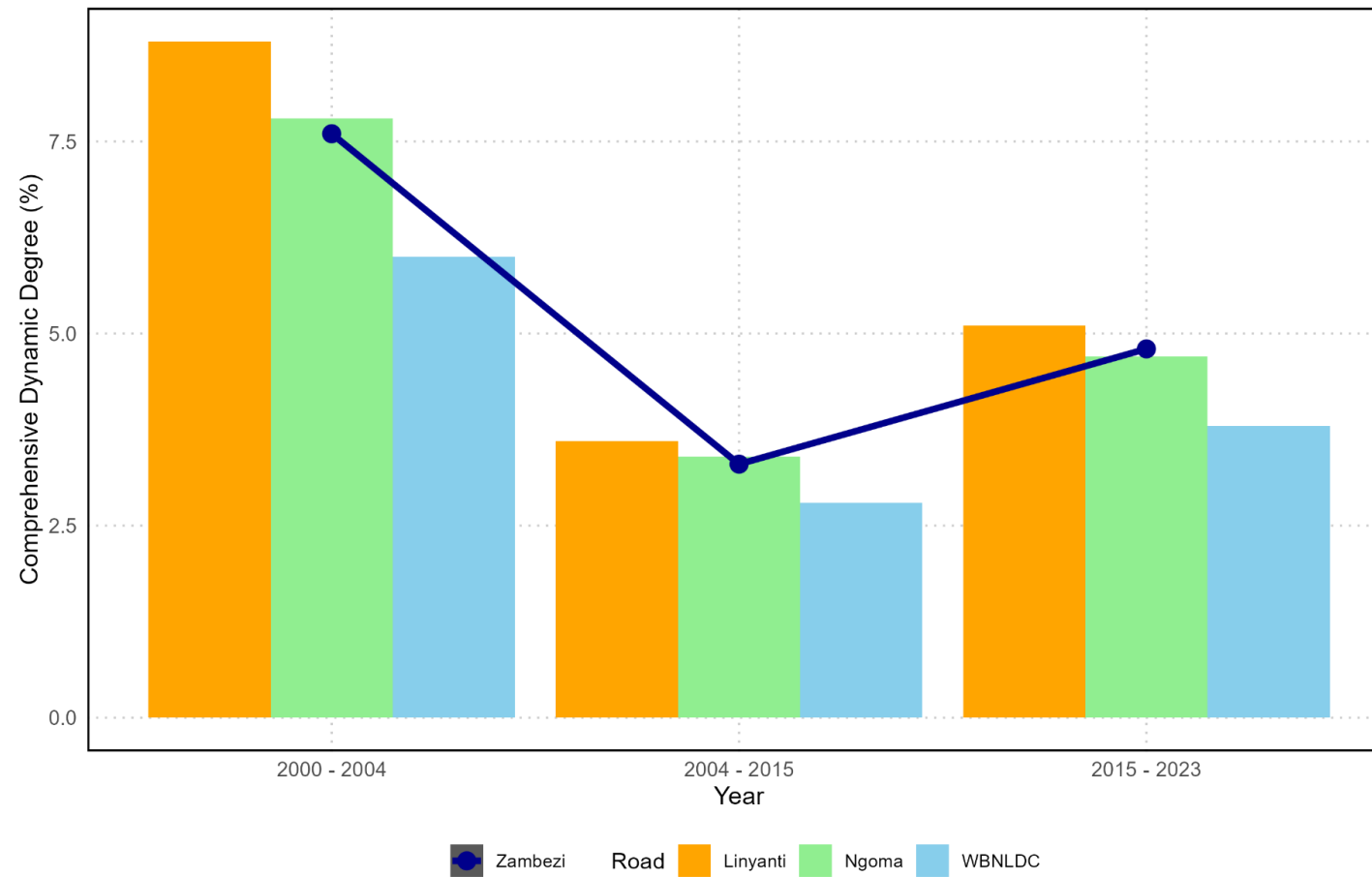


Figure 7: Comprehensive land use dynamic degree within the Zambezi Region. Source: Authors' own design.

Table 6: Changes in cultivated land along the WBNLDC and regional roads in the Zambezi Region. Source: author's calculations.

Land use									Land use change				
									2000	2004	2015	2000 - 2023	
									-	-	-		
Buffer Zone	2000		2004		2015		2023		2004	2015	2023		
	km ²	%	km ²	%	km ²	%	km ²	%	km ²	km ²	km ²	km ²	%
WBNLDC	227.1	26.8	246.6	26.0	321.2	28.8	399.1	27.4	19.6	74.6	77.9	172.1	75.8
Ngoma-T807	147.6	17.4	162.4	17.2	243.0	21.8	226.9	15.6	14.9	80.6	-16.1	79.4	53.8
Linyanti-M0125	472.3	55.8	537.9	56.8	549.6	49.3	830.6	57.0	65.5	11.7	281.0	358.3	75.9
Total	846.9	100.0	946.9	100.0	1113.8	100.0	1456.7	100.0					
Katima	50.9	43.0	66.4	52.1	76.4	41.7	100.1	49.2	15.5	10.0	23.7	49.1	96.4
Kongola	67.5	57.0	60.9	47.9	106.8	58.3	103.2	50.8	-6.5	45.8	-3.6	35.7	53.0
Total	118.4	100.0	127.4	100.0	183.1	100.0	203.3	100.0	-	-	-	-	-

Table 7: Built-up area changes along the WBNLDC and regional roads in the Zambezi Region. Source: author's calculations

Land use									Land use change				
									2000	2004	2015	2000 – 2023	
									-	-	-		
Buffer Zone	2000		2004		2015		2023		2004	2015	2023		
	km ²	%	km ²	%	km ²	%	km ²	%	km ²	km ²	km ²	km ²	%
WBNLDC	2.9	20.6	4.7	19.4	4.1	16.7	8.6	16.0	1.8	-0.6	4.5	5.7	194.9
Ngoma-T807	3.9	27.3	6.7	27.8	6.7	27.5	27.2	50.6	2.8	0.0	20.4	23.3	603.8
Linyanti-M0125	7.4	52.0	12.7	52.8	13.6	55.8	17.9	33.4	5.4	0.9	4.3	10.5	143.4
Total	14.1	100.0	24.1	100.0	24.4	100.0	53.7	100.0	-	-	-	-	-
Katima	9.1	88.2	13.3	87.9	11.2	87.8	23.1	80.0	4.2	-2.1	11.9	14.0	153.3
Kongola	1.2	11.8	1.8	12.1	1.6	12.2	5.8	20.0	0.6	-0.3	4.2	4.5	370.9
Total	10.3	100.0	15.1	100.0	12.8	100.0	28.9	100.0	-	-	-	-	-

4.4 Discussion

Overall, the findings support the idea that road construction promotes accelerated land conversion near transportation infrastructure as indicated in previous studies elsewhere (Sanchez, 2000; Jedlička et al., 2019; Zheng et al., 2021). A notable decline in forests and grasslands, as previously documented (Kamwi et al., 2017; Gbagir et al., 2019), was attributed to cultivated land and built-up area expansion. While prior research in the region has acknowledged road development as a significant driver of land use change, it often lacked a focus on the road types, timelines, and their links to regional development.

This study addressed these gaps, examining how roads affect land use change and identifying which roads are more conducive to regional development and rural livelihoods. The use of a 10 km buffer along all roads facilitated effective spatial analysis, while a time series analysis provided temporal insights by comparing changes before and after road developments. A combination of single and comprehensive dynamic degrees of change enabled the comparison across land uses and locations over time. Developmental policies and activities in the Zambezi Region and Namibia were analysed to contextualise the drivers of change. The integrated land use plan for the Zambezi Region, for instance, set objectives such as establishing an agricultural hub by 2020 and improving rural and urban livelihoods by 2025 (Ministry of Lands and Resettlement [MLR], 2015).

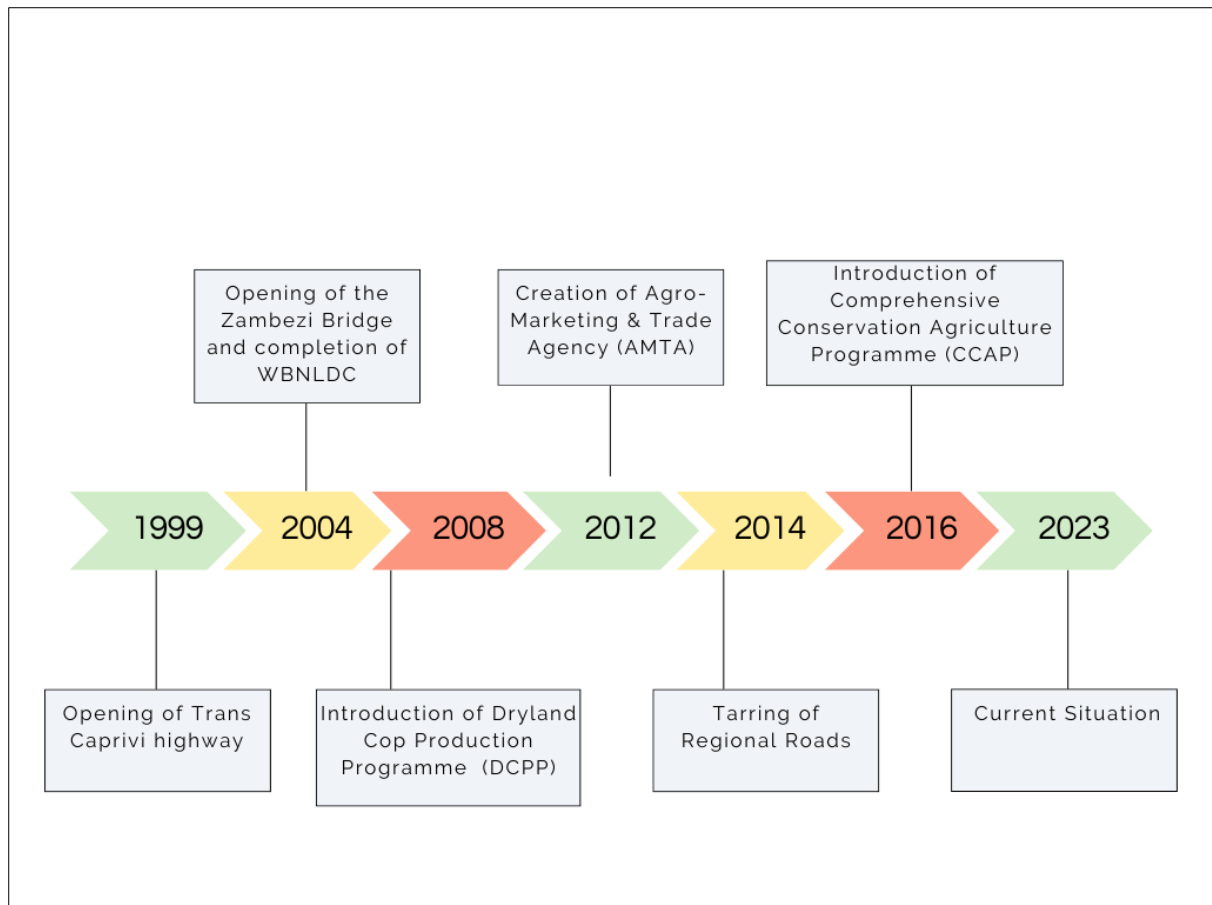


Figure 8: Policies and developmental activities in Zambezi Region. Source: Authors' own design based on (MLR, 2015, Ministry of Agriculture, Water and Forestry [MAWF], 2017; Nakale, 2022; Kiesel et al., 2022)

The opening of the Trans-Caprivi Highway in 1999 was a pivotal moment for the region's development, coinciding with an increase in cultivated land. This highway aimed to connect farmers to broader markets, thus improving livelihoods. Subsequent infrastructure, such as the Zambezi River bridge, further enhanced connectivity, promising economic opportunities beyond the region's borders. Despite these advancements, cultivated land expansion rates after 2004 were lower than anticipated, suggesting the corridor's limited impact on agricultural production. Consequently, the Government of Namibia introduced the Dryland Crop Production Programme (DCPP) in 2006, targeting farmers in northern communal areas, including the Zambezi Region. This programme sought to improve crop production through better seeds, fertilisers, and farming techniques (MAWF, 2017; Nakale, 2022; Kiesel et al., 2022). However, cultivated land expansion during this period remained modest, indicating that the corridor's completion had minimal influence on agricultural productivity, even when coupled with DCPP initiatives.

The tarring of regional roads, completed in 2014, marked another significant milestone. This coincided with the launch of the Comprehensive Conservation Agriculture Programme (CCAP) in 2015, which aimed to enhance the resilience of small-scale farmers to climate change through conservation agriculture (MAWF, 2017; Nghishidivali, 2023). This period recorded the highest expansion of cultivated land and built-up areas, underscoring the significant impact of road tarring on agricultural expansion compared to the previous periods. Our observations confirmed that different road types have varying impacts on land use patterns (Su et al., 2014).

Cultivated land expansion was most prominent along the Linyanti Road, while built-up areas expanded significantly along the Ngoma Road. This highlights the role of regional roads in connecting smaller settlements and facilitating both cultivated land and built-up area growth. The conditions around Ngoma, including its proximity to conservancies, agricultural land, and human settlements, likely encouraged farming activities along the road (MLR, 2015; Gbagir et al., 2019). Enhanced road connectivity, particularly through road tarring, has further implications for regional development. Improved accessibility has increased tourist influx to the Zambezi Region, prompting the construction of additional hotels and lodges to accommodate rising demand (Kavelage et al., 2021).

This agrees with a study in Malaysia that highlighted that the regional roads play a major role in connecting settlements to the labour market and resource allocation, thus influencing the growth rate of populations in settlements (Shashyna et al., 2021; Jain & Gupta, 2023). The population in the study area was 79,826 people in 2001, growing at an annual rate of 1.3% to reach 90,596 people in 2011 (Namibia Statistics Agency, 2011). This growth was slower than the 1.8% annual increase recorded between 1991 and 2001 (Namibia Statistics Agency, 2011). However, the most significant population increase occurred after the tarring of regional roads, with an annual growth rate of 3.8% between 2011 and 2023. During this period, the population surged to 142,373 by 2023, suggesting that improved road infrastructure may have played a key role in driving this rapid growth (Namibia Statistics Agency, 2024). This strong population increase and built-up area increase after the tarring of the roads supports the idea that regional roads are much more important for regional development. Furthermore, improved connectivity has facilitated economic activity,

as farmers in the region frequently travel to Katima Mulilo, a growing economic hub, to sell surplus produce (Dlamini, 2017; Nakale, 2017; Corry & Voigts, 2023; Zeller, 2009), leveraging the road's role in regional trade and the positive impact of enhanced connectivity on their livelihoods.

Kongola and Katima Mulilo have experienced expansion in terms of both cultivated land and built-up area, which could either be attributed to influences from both regional and development corridors and thus becoming potential growth poles along the corridors. It could also be due to demographic and strategic locations as previously mentioned in studies. Clearly, the WBNLDC has also enhanced its accessibility across borders, resulting in increased commercial activities and multinational investments in services such as petrol stations, supermarkets, hardware stores, and banks (Zeller, 2009). In addition, the increase in built-up areas at Katima Mulilo could be attributed to its strategic location between major tourist destinations, the Chobe River in Botswana, Victoria Falls in Zimbabwe, and Livingstone in Zambia, which has made it a popular stopover or the start of a trip to these larger attractions that are all reachable through roads. While this study has not explored these changes from other perspectives, such as employment opportunities or economic activities, future research could focus on comparing nodes along the corridor to better understand the factors contributing to built-up area expansion at specific localities.

Previous studies in the Zambezi Region have indicated that the establishment of trade routes, such as the *WBNLDC*, often leads to the growth of settlements and farms near roads, contributing to increased cultivated land and built-up areas around transportation infrastructure (Gbagir et al., 2019; Colpaert et al., 2013). Our study complements these findings by observing similar trends, with cultivated land expansion occurring notably around settlements. However, we found that the rate of cultivated land expansion was significantly lower along the *WBNLDC* compared to regional roads. This disparity suggests that regional roads, such as the Linyanti-M0125 and Ngoma roads, which experienced greater expansions in both cultivated and built-up areas, are more conducive to localised changes.

Based on the results and policies analysed, our results suggest that the *WBNLDC* might not have achieved its goal of attracting substantial agricultural investments or

significantly improving rural livelihoods. This indicates that development corridors may not significantly improve rural livelihoods as initially promised. While such corridors facilitate trade and international cooperation, they should not replace policies aimed at local development. The limited cultivated land expansion along the WBNLDC implies that its expected outcomes, particularly in fostering agricultural growth, have not fully materialised. These actual outcomes reflect some of the broader challenges associated with development corridors in Africa. As noted by Müller-Mahn (2017), such corridors are often framed as pathways to modernity and progress, but they can also function as 'dreamscapes' that prioritise external economic interests over the needs of local communities. In this regard, while the WBNLDC was expected to catalyze agricultural investment, its impact on local livelihoods has been limited, raising questions about the effectiveness of such corridors in delivering the promised benefits. These findings also suggest that development strategies may succeed in regions with pre-existing infrastructure, as seen in parts of Asia (e.g., Xiao et al., 2024; Zheng et al., 2021), where large-scale corridors have fostered land use changes and economic growth. However, the true success depends on the region's specific context and the involvement of local stakeholders, particularly in rural areas, to ensure their promises materialise in an African setting. In this case, regional roads have demonstrated a more immediate and tangible impact on land use and livelihoods, emphasising the importance of localised infrastructure for sustainable rural development.

This study deliberately focused on land use changes and their implications within the Zambezi Region, using cultivated land and built-up area as key indicators of livelihoods given its cultural and economic significance providing first indicator of the potential impacts on the livelihoods. This calls for a future broader analysis encompassing multiple perspectives and proxies through direct measurements of the livelihood dynamics, such as household surveys to indicate population changes, land ownership patterns, and employment opportunities to capture shifts in livelihood and economic activity resulting from infrastructure developments.

4.5 Conclusion

This study assessed the impact of the *WBNLDC* corridor and regional roads on land use changes in the Zambezi Region from 2000 to 2023, focusing on cultivated land and built-up area expansion as proxies for improved livelihoods. Results revealed

increased cultivated land and built-up area while forest and grasslands decreased throughout the study area. It became clear that while cultivated land and built-up areas expanded across all roads, most changes occurred along regional roads after being tarred, suggesting that they are more responsible for land use changes than the development corridor. This implies that the developmental outcome of the corridor remains rather limited and questions its contribution to poverty eradication and improving livelihoods. This suggests that large-scale infrastructure projects may not fully realise their potential at a local level without local development policies.

Software

Data processing and analysis were performed using GEE and Esri's ArcGIS Pro.

Data Availability Statement

The data supporting this study's findings are available upon request from the corresponding author.

Disclosure Statement

The authors confirm that there are no conflicts of interest to declare.

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5. Development Corridors in Southern Africa: Navigating Unfulfilled Visions and Complex Realities

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Abstract

Governments promote development corridors as a "win-win" strategy for regional integration, yet literature reveals conflicting perspectives on whether these corridors foster broad based growth or lead to uneven development. This study utilises a 33-year panel of harmonized nighttime lights (NTL) as a proxy for development to assess how these expectations materialise along the Walvis Bay Ndola Lumbumbashi Development Corridor (WBNLDC) in Southern Africa. Findings reveal that while economic activity has increased, this varies across countries, with growth concentrated in mining areas, border towns, and port cities. This growth is primarily tied to the extractive industries and logistics, reflecting a selective integration and enclave pattern, with few spillovers to surrounding areas and little evidence of broader corridor-wide agglomeration. The results imply that the expected outcomes with respect to regional integration and agglomeration have not yet materialised, warranting a need for coordinated efforts among stakeholders to achieve a more balanced growth.

Keywords

Infrastructure-led development, development corridor, regional development, nighttime lights, selective integration, extractive enclaves

5.1 Introduction

Development corridors are often promoted as a spatial tool for economic growth, particularly in the Global South. The rise of these corridors in Africa can be attributed to the new scramble for Africa's resources (Carmody, 2017; Müller-Mahn et al., 2021). Governments and private businesses are capitalising on the need for investors to transport goods to foster economic development between production sites and global markets (Mulenga, 2013; Dannenberg et al., 2018; Enns, 2018). The governments describe this as a win-win situation for regional economic integration, in which they promise to channel investments along the corridors, enabling firms to engage in global markets and establish trade hubs (Beer and Arkwright, 2003; Mbekeani, 2010).

However, the outcomes of corridors with respect to regional development remain poorly understood. Previous literature on development corridors indicates that while these corridors have potential to stimulate economic development, they often fail to create a balanced development along their routes (Kavelage et al., 2021; Yang et al., 2024). Researchers also highlight that the concept of transport corridors is not new to Africa. Historically, they were used as tools to extract and export natural resources from African countries to European colonial powers (Jedwab and Moradi, 2016; Kirshner and Baptista, 2023). Although today development corridors are promoted as a win-win infrastructure, other researchers argue that these colonial legacies are being modernized and replaced; however, they still serve the interests of resource extractives and reinforce inequalities from the colonial past (Enns and Bersaglio, 2020; Kirshner and Baptista, 2023)

Research reveals that infrastructure projects often fail to fully account for the complexity of regional political economies, governance fragmentation, and spatial inequalities (Dannenberg et al., 2018; Enns, 2018). Recent scholarship emphasises that corridors are political and economic projects that can deepen extractive patterns and reinforce existing spatial inequalities (Zajontz, 2024). Additionally, there is lack of comprehensive analysis of the outcomes of development corridors, which is further complicated by the limitations of the existing datasets. Traditional datasets for regional development, such as national datasets and Gross Domestic Product (GDP), are typically aggregated at the national level, making it challenging to analyse corridors that span multiple countries and regions (Henderson et al., 2011; Frick and Rodríguez-Pose, 2019). However, the use of nighttime lights (NTL) datasets to measure economic activity and urbanization has gained attention in data-scarce regions (Henderson et al., 2011; Gibson, 2021). NTL data offers valuable insights into local level economic changes, making a helpful tool for assessing development outcomes in areas where official statistics are limited or unreliable (Weidmann and Schutte, 2017; Frick and Rodríguez-Pose, 2019). However, despite its growing use in Asia, like the Belt and Road Initiative (BRI), NTL's application in African contexts has been limited.

Methodologically, this paper employs NTL data to offer a nuanced understanding of the developmental outcomes of African cross-border corridors. Conceptually, we evaluate whether development corridors catalyze a pathway of corridor-wide integration and agglomeration (Scenario A) or manifest as infrastructures of circulation characterised by selective integration and extractive enclaves (Scenario B).

Empirically, this study focuses on the Walvis Bay Ndola-Lubumbashi Development Corridor (WBNLDC), which aims to facilitate trade and economic integration by connecting the port of Walvis Bay to the Copperbelt region of Zambia and the DRC. Namibia has positioned itself as a logistics hub for the region by aligning the national development plans with infrastructural development, including the WBNLDC, to support its logistics dream (*Namibia's fourth national development plan: NDP_4: 2012/13 to 2016/17*, 2012; Japan International Cooperation Agency (JICA), 2015). Since the corridor's completion in 2004, the Namibian government has channeled investments in upgrading infrastructure along the corridor and Walvis Bay port. These efforts, including the extension of the port area as well as creation of a national logistics master plan, demonstrate Namibia's commitment to making the corridor a preferred route and a key driver for achieving its logistical hub (Namibian Ports Authority (NAMPORT), 2019; African Development Bank Group, 2020). The corridor provides a shorter, more efficient route for DRC and Zambia to the Atlantic Ocean and the western countries. This makes it a key driver of economic growth and regional growth to both countries (Lusaka Times, 2023). However, after 20 years in operation, a systematic analysis of the developmental impact of the corridor is still lacking. The objective is not to estimate a single causal impact parameter for the corridor, but to identify macro-spatial development pattern associated with corridor proximity under different mechanisms.

The following sections of the paper are organised as follows: Section 2 introduce the literature on corridor-led development and sets out the two structural pathways through which it may unfold. Section 3 presents the case study and the methodology adopted in the study. Sections 4 and 5 present and discuss the spatial patterns of the

economic activity along the WBNLDC as outline in the framework in section 2. Finally, section 6 concludes by summarising the findings and implications of the study.

5.2 Development Corridors and Regional Development

Rather than treating development corridors as neutral infrastructures whose outcomes depend primarily on local context or implementation quality, this paper conceptualises corridors as politically and economically embedded projects that reshape space through their role in facilitating capital circulation, logistical integration, and resource extraction. From this political economy perspective, development corridors are integral to broader regimes of accumulation and territorial restructuring, linking selected regions to global commodity chains while bypassing or marginalising others. Uneven spatial outcomes are therefore not necessarily deviations from intended development trajectories but may reflect the structural logics of corridor-led development itself, including capital intensity, governance selectivity, and the prioritisation of circulation over local value creation (Enns, 2018; Dannenberg et al., 2018; Scholvin, 2021).

The two scenarios developed below (Figure 9 and 10) are accordingly framed as mechanism-based ideal types that capture distinct political–economic pathways through which development corridors can shape regional development. They are not normative benchmarks of success or failure but analytical lenses that guide the interpretation of observed spatial patterns.

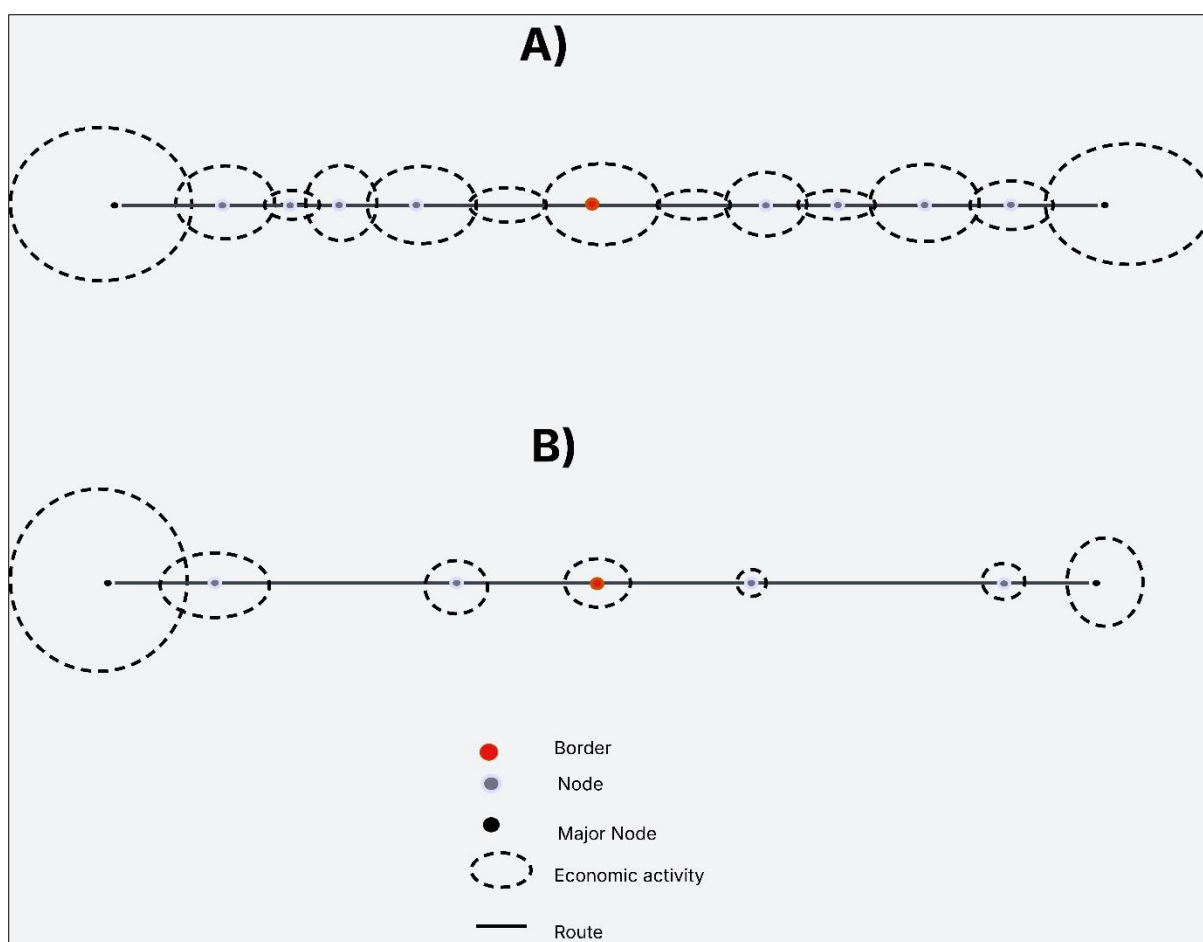


Figure 9: Development corridor outcomes. Source: Authors' own design

5.2.1 Scenario a: Integration and Agglomeration

Development corridors are best conceptualised as a coordinated bundle of transport infrastructure, logistics services, and regulatory arrangements rather than as “roads alone” (Kunaka and Carruthers, 2014). In Scenario A, corridor investments reduce travel time, transport costs, and uncertainty, thereby increasing accessibility and market access for firms and households (World Bank, 2009; Donaldson and Hornbeck, 2016; Redding and Turner, 2015). Lower spatial frictions facilitate trade, specialisation, and mobility, creating conditions under which agglomeration dynamics may emerge endogenously (Krugman, 1991; Glaeser, 2010; Puga, 2010).

Within this mechanism, development corridors are expected not only to connect major urban nodes but also to integrate intermediate towns and surrounding rural areas into wider markets. Improved connectivity may incentivise firm entry, encourage diversification beyond primary production, and stimulate cumulative processes of clustering, labour mobility, and knowledge spillovers (Mulenga, 2013; Dannenberg et al., 2018). Crucially, for these dynamics to translate into broader regional development, political and institutional arrangements must enable the redistribution of corridor-generated rents and foster local backward and forward linkages, rather than allowing gains to remain concentrated at a small number of nodes (World Bank, 2009; Morris et al., 2019).

Assumptions, boundary conditions, and competing explanations

Scenario A is contingent on strong complementary conditions. Border facilitation, reliable energy supply, access to land, skills availability, and effective corridor governance are necessary to prevent “weak links” in the transport – logistics - regulation system from constraining broader development effects (Kunaka and Carruthers, 2014). Moreover, spatial economic theory implies that reductions in trade costs can either diffuse economic activity or reinforce spatial concentration, depending on the strength of scale economies and relative market size (Krugman, 1991). Diffusion should therefore be treated as an empirical possibility rather than a presumption (Faber, 2014). Alternative explanations for observed growth patterns include concurrent urbanization strategies, electrification programs, or macroeconomic shocks coinciding with the corridor’s completion, all of which complicate causal attribution.

Rather than testing firm-level or price effects directly, Scenario A generates observable spatial signatures in nighttime lights, which capture the extent and distribution of electrification, built-up expansion, and economic activity. If corridor-induced integration and agglomeration dynamics dominate, development effects should be spatially diffuse rather than narrowly concentrated.

Under Scenario A, we should observe spatially diffuse growth patterns in nighttime lights. Average light intensity would rise in corridor-proximate areas relative to more distant controls following 2004 corridor completion. Positive effects would extend beyond major urban nodes into intermediate towns and rural stretches along the route, indicating spatial spillovers and diffusion dynamics. Over time, sharp light gradients between corridor cores and surrounding periphery would decline as improved connectivity reduces spatial contrast. Finally, light growth trajectories would exhibit temporal persistence, consistent with cumulative and self-reinforcing agglomeration processes rather than short-lived, transient shocks.

Empirically, these implications are examined using harmonised nighttime lights data combined with a spatial difference-in-differences event-study design. Corridor exposure is defined using distance-based buffers around the transport route, and effects are estimated relative to matched control areas. Event-study coefficients are interpreted as patterns consistent with corridor-induced integration, while acknowledging that nighttime lights measure spatial concentration of activity rather than inclusive or distributional development outcomes.

5.2.2 Scenario B: Selective Integration and Extractive Enclaves

In Scenario B, development corridors function as infrastructures of circulation that enable selective territorial integration into global commodity and production networks,

rather than as mechanisms designed to foster corridor-wide development (Enns, 2018). Corridor investments primarily facilitate commodity and trade flows between landlocked production zones, processing sites, and global markets, while concentrating investment, governance attention, and upgrading opportunities at a limited number of strategic nodes such as mines, border crossings, ports, and special economic zones (Gereffi et al., 2005; Coe et al., 2008).

From this political economy perspective, corridors do not integrate territories uniformly; instead, they selectively connect locations that are functional for extractive accumulation and logistical efficiency, while bypassing or marginalising intermediate regions. This mechanism aligns with critical scholarship that conceptualises development corridors as spatially selective projects embedded in regimes of extractive capitalism and logistical restructuring (Dannenberg et al., 2018; Lesutis, 2019; Scholvin, 2021). Although corridors are often promoted through win-win narratives of regional integration, empirical research documents how such projects produce enclave-style development outcomes, with benefits accruing to a narrow set of actors and places, and limited spillovers to surrounding areas (Enns and Bersaglio, 2020; Phelps et al., 2015).

Assumptions, boundary conditions, and competing explanations

Scenario B is most plausible where corridor benefits are tightly coupled to global commodity cycles, where investment is capital-intensive, and where local institutional and productive capacities remain weak (Morris et al., 2019). Under these conditions, development corridors tend to amplify existing spatial hierarchies by privileging extractive and logistics nodes over intermediate regions. The scenario predicts that corridor-associated gains are highly sensitive to global demand fluctuations and that

observed growth patterns reflect the selective integration of territories into global markets rather than broad based regional transformation. A key competing explanation is a “commodity boom only” mechanism, whereby spatially concentrated growth reflects global price dynamics independent of corridor infrastructure, reinforcing the need for cautious interpretation of empirical results. Scenario B generates distinct spatial signatures in nighttime lights, reflecting selective integration and enclave-style development rather than corridor-wide transformation. Scenario B predicts spatially selective concentration patterns. Post-2004 light increases would concentrate in strategic nodes such as: mining towns, border crossings, ports, and major cities; rather than evenly distributed along the entire corridor. Large intermediate rural sections would remain comparatively dark or show limited change, indicating weak spatial spillovers to non-nodal areas. Cross-country and subregional heterogeneity in light trends would prove pronounced, reflecting differential exposure to extractive industries, logistics functions, and institutional contexts. Temporal light changes would coincide with periods of global commodity market expansion, suggesting sensitivity to broader economic cycles rather than infrastructure timing alone.

Empirically, these implications are assessed using spatial trend analysis (Theil-Sen slope and Mann-Kendall tests) and a spatial difference-in-differences event-study framework applied to harmonised nighttime lights data. Heterogeneity is explored across countries, regions, and selected towns along the corridor. Rather than establishing definitive causal attribution, the analysis evaluates whether observed spatial patterns are more consistent with selective integration and extractive enclave dynamics than with corridor-wide integration and agglomeration. (Figure 9 and 10).

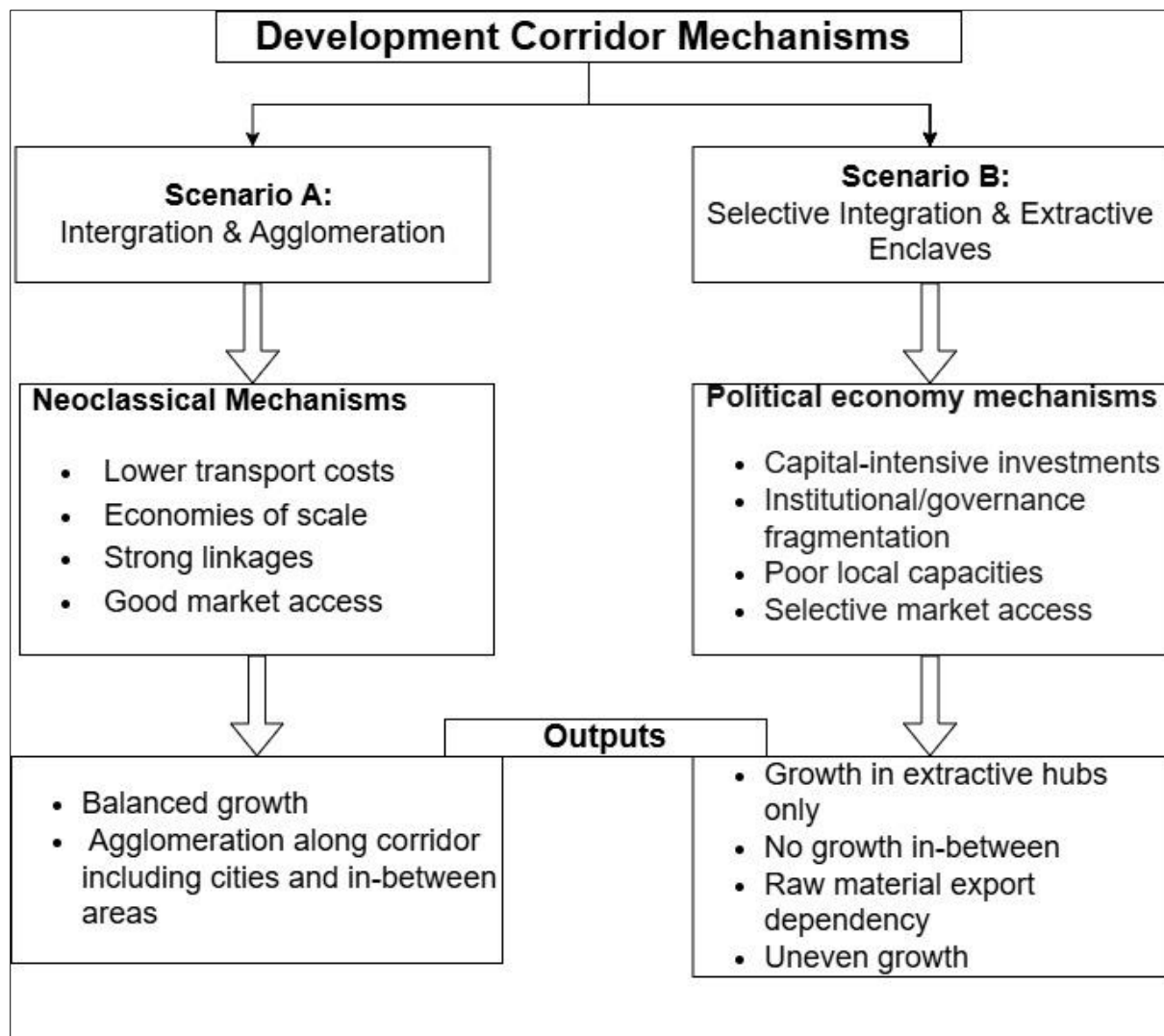


Figure 10: Comparison between the Scenario A and B on possible mechanisms and outcomes of development corridors. Source: Authors' own design

5.3 Case Study of the WBNLDC

The empirical analysis focuses on the WBNLDC (Figure 11), using nightlight data as a proxy for development. The WBNLDC's development unfolded in two key phases. The first phase was completed in December 1999 with the construction and opening of the Trans Caprivi Highway, linking Namibia's Zambezi Region to the rest of the country (Zeller, 2009). However, the corridor only became fully operational in 2004 following the completion of the Zambezi Bridge, which established a direct connection between Namibia and Zambia, extending the corridor's reach to the DRC. The corridor connecting the Zambezi Region, previously known as the Caprivi region, to the rest of Namibia and Zambia is not entirely a new phenomenon for the region. The Zambezi region's strategic geographical position has been previously planned and utilised as a stepping-stone to access the hinterlands and their resources during the colonial era, primarily through the Zambezi River as a transport route (Zeller, 2009; Kangumu, 2011; Rizzo, 2012). Although this initiative did not materialise, a similar vision has been introduced under the WBNLDC, this time via a road corridor to connect the Copperbelt of Zambia and the DRC to Namibia's port of Walvis Bay, and subsequently to the global market. This case study was selected due to its historical context as well as the Namibian government's alignment of its developmental plans with infrastructure planning. Given the importance of this corridor to the region and the timeline of the development corridor after 20 years of operation, a systematic analysis of the economic activity along the corridor is warranted. Analysing the WBNLDC allows us to assess whether such mega-infrastructure projects foster balanced growth along the corridor, as proposed by the optimistic perspective, or whether they contribute to unbalanced development and growing regional disparities, as highlighted in the pessimistic view.

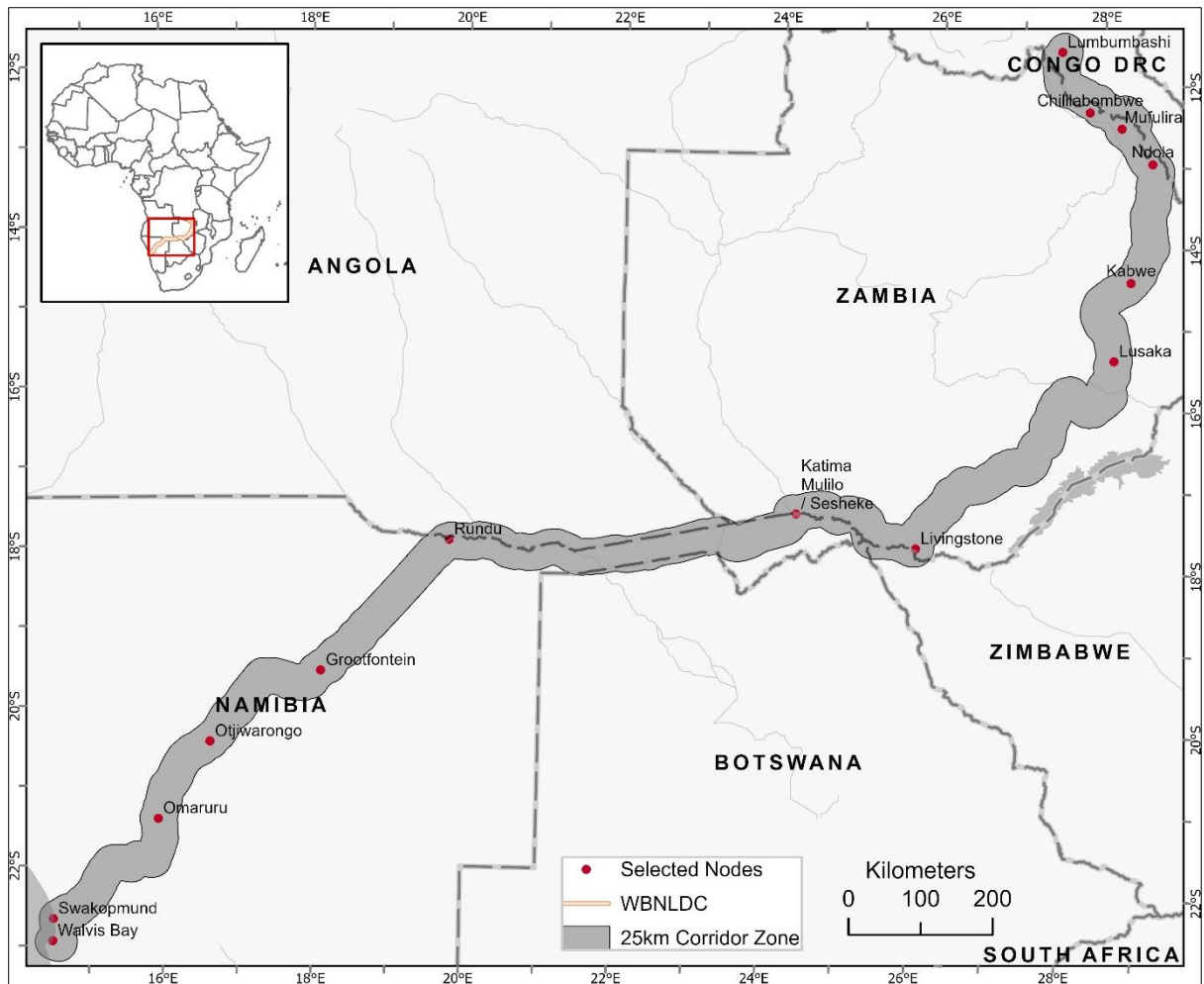


Figure 11: Study area. Source: Authors' own design

5.3.1 Dataset

Nighttime Lights Data

We draw our empirics from the nighttime lights (NTL) dataset along the corridor. The widely used nighttime lights data from the Defense Meteorological Satellite Program (DMSP) - Operational Line-scan System (OLS) has been instrumental in measuring economic activities and development at various scales globally (Elvidge et al., 2001). This dataset gained fame after being used in a landmark study by Henderson and others in 2012 (Henderson et al., 2012). Since then, it has been employed in numerous studies to track urban development, economic activity, labour productivity, regional

inequality and land cover change (Chen et al., 2024; Li and Cao, 2024). However, these datasets are not publicly available beyond 2012, which limits their use for analysis after 2012. The introduction of nighttime data from the Visible Infrared Imaging Radiometer Suite (VIIRS) has facilitated the assessment of economic development in recent years (Zheng et al., 2022; Ye et al., 2023a). Despite improvements in resolution and the addressing of issues like oversaturation, VIIRS data are only available from 2012 onward, necessitating their combination with DMSP data for time series analysis (Chen et al., 2024). However, this process proved difficult due to differences in spatial and radiometric capabilities, warranting calibration. As a result, various attempts have been made to improve the quality and harmonise the datasets (Zheng, Weng and Wang, 2019; Zhao et al., 2022; Li et al., 2023). A recent harmonisation product, the Pixel-Corrected Night Lights dataset (PCNL), accounts for saturation and blooming effects commonly found in popular harmonisation products (Li et al., 2023). Although exhibiting inter-annual fluctuations, this new global dataset is highly correlated with human development indicators, such as GDP and population (Li et al., 2023; Li and Cao, 2024), making it valuable for our study. Moreover, it enables comparisons among different countries through which the development corridor passes, thereby addressing the limitations of relying on datasets from various sources. Therefore, we utilised the Pixel-Corrected Night Lights (PCNL) dataset in this study. We use the annual PCNL composites (1992 – 2024) at ~ 1km spatial resolution as provided by Li et al., 2023. These raster files were aggregated to the 1km grid cells using the mean NTL in each cell. The outcome variable is $\log(\text{NTL} + 1)$, to account for zero observations while moderating the influence of high intensity pixels.

5.3.2 Methods

Theil-Sen Median and Mann-Kendall Tests

We used the Theil-Sen median slope to analyze the dynamic trend in nighttime lights data at the individual pixel level along 25 km on either side of the corridor, before and after its completion in 2004. Theil-Sen slope is the most widely used non-parametric trend prediction model because it does not assume linearity or normality, and is suitable for datasets where noise may affect trends (Sen, 1968; Ye *et al.*, 2023b; Li and Cao, 2024). The following formula was used to calculate Theil-Sen Median Slope:

$$Slope = median\left(\frac{NTLi - NTLj}{j - i}\right)$$

(1)

Where $NTLi$ and $NTLj$ are the nighttime light intensities at the times i and j , the slope represents the strength of NTL over time.

Once we determined the presence of the trend, we assessed its significance using the Mann-Kendall test. The Theil-Sen Slope and Mann-Kendall are often applied together to detect trends and their significance (Mann, 1945; Kendall, 1948; Huang and Wang, 2019; Li, Wu and Niu, 2024; Wang *et al.*, 2024). The following equations have been used to calculate and assess the significance of the trend.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n sign(NTL_j - NTL_i)$$

(2)

$$Z = \begin{cases} \frac{S - 1}{\sqrt{var(S)}}, & S > 0 \\ 0, & S = 0 \\ \frac{S + 1}{\sqrt{var(S)}}, & S < 0 \end{cases}$$

(3)

Where $var(s)$ is as follows:

$$var(s) = \frac{n(n-1)(2n+5)}{18}$$

(4)

$$sign(NTL_j - NTL_i) = \begin{cases} 1, NTL_j - NTL_i > 0 \\ 0, NTL_j - NTL_i = 0 \\ -1, NTL_j - NTL_i < 0 \end{cases}$$

(5)

Whereby NTL_j and NTL_i are the nighttime light intensities at time period j and i , n is the period of years, the sign is the sign function, and Z is the significance of the trend. S indicates the increasing or decreasing pairs, while $vars$ adjusts for a number of observations.

Spatial Differences-in-Differences with fixed effects event-study regression

We employ a quasi-experimental differences-in-differences model (DID), utilising an event-study on a matched sample generated through propensity score matching (PSM). The DiD method is helpful as it removes time-invariant biases before conducting the association analysis, including seasonality, differences in starting levels that might affect the NTL lights in different areas (Barton-Henry and Wenz, 2022). The difference-in-differences test assumes that, in the absence of the treatment, the treated and control areas would have followed the same trend over time (Lechner, 2011; Callaway and Sant'Anna, 2021). Acknowledging the inherent challenges in isolating the causal effect, our methodology combines an event-study with grid cell fixed effects estimations. We use PSM to enhance the comparability of our groups, creating a balanced experiment where treated and control cells share

similar characteristics before the treatment in 2004 (Rosenbaum and Rubin, 1983; Blundell and Costa Dias, 2000). The method had been proven to remove bias in control and treated groups before treatment and ensure that both groups have same distribution (Rosenbaum and Rubin, 1983).

We established treated areas within 25 km of the corridor. This threshold is justified by our Distance-Decay Analysis (Appendix 1), which shows that significant economic intensity is primarily concentrated within this proximity. Control areas were located between 30 km and 110 km from the road. This threshold is also consistent with previous studies in Africa, which suggest that the effects of economic activity and infrastructure in African contexts are primarily concentrated near road infrastructure (Biber-Freudenberger et al., 2025). In contrast, control areas were located far from roads, ranging from 30 km to 100 km. While these cells are far enough to be unaffected by the corridor's immediate logistics, they provide a comparable geographic context once matched (Storeygard, 2016).

To ensure a robust baseline, we extended the analysis backwards to 1992 using the PCNL dataset. The pre-treatment period is defined as 1992–2003, providing a 12-year window to verify parallel trends. Matching was performed within-country using 2003 baseline covariates, including log (NTL+1) and population density (LandScan). This ensures that our treated and control cells had identical distributions of light and population before the corridor's completion.

The event-study regression was carried out to estimate the associations of the corridor completion for each year relative to the treatment year 2004, using the following equation:

$$NTL_{log,it} = \alpha_i + \delta_t + \sum_{k \neq 1} \beta_k (Treated_k \times RelativeYear_{it}^k) + \epsilon_{it}$$

(6)

Where $NTL_{log,it}$ is the log of nighttime light intensity for grid cell_i in year_t, α_i is the grid cell fixed effects (geographic location) and δ_t is the yearly fixed effects for each cell. $Treated_k$ is a binary indicator which is 1 if the grid cell_i is in the treated group and 0 if it is in the control group, $RelativeYear_{it}^k$, represents dummy variables where each k represents a specific year relative to the treatment year (2004). β_k is the coefficient of interest representing the estimated average causal effect of corridor proximity on NTL_{log} in $RelativeYear$ k, relative to the pre-treatment period (k=-1) and ϵ_{it} is the error term.

Country-specific heterogeneity analysis

To further explore the potential heterogeneity in treatment effects across different countries, regions, and towns, the fixed effect event-study regression model is re-estimated separately for each country. This analysis gives a summary of how the corridor proximity and NTL may vary across diverse geographic and socioeconomic environments, which are further explored in the discussion sections.

5.3.3 Robustness Checks

Several robustness checks were carried out to address methodological assumptions and heterogeneity. Firstly, we varied the treatment buffer to test for partial decay patterns whereby we created 3 buffers: a) narrow buffer (0 – 10 km vs 30 -100km) b) main specification (0-25 vs 30-100km) and c) wide buffer (0 -50km vs 50 – 100km) in order to explain that our results are not sensitive to buffer definitions or estimation methods (see Appendix A.1). We also interacted a distance-decay with different

distance bands such as 0-5km all the way until 100km and more with a post 2004 indicator, always using the furthest distance 100+ km as the reference category (See Appendix A.2). We also compared the traditional two-way fixed effects (TWFE) estimates with the Callaway-Sant'Anna (2021) estimator to assess the sensitivity to DiD critiques (Appendix A.3). As summarised in Appendix A.3, the estimates remain consistent between the Two-Way Fixed Effects (TWFE) and the Callaway and Sant'Anna (2021) estimators, with the strongest effects consistently observed within the narrowest (0–10km) corridor core. We subsequently selected 25km as a net to ensure we do not miss any spillover effects.

5.3 Results

5.3.1 Spatial Distribution and Trend Variation of NTL Along the WBNLDC

Figure 12 illustrates the spatial distribution of NTL within 25km along the WBNLDC, which serves as a proxy for development in terms of economic activity from 1992 to 2024. The NTL values were categorised into five levels to indicate no, low, mid, high, and max light levels in the study area. Economic activities were present in the area even before its completion in 2004, as observed by NTL in 2004; however, the extent was much smaller. A map from 2004 serves as a comparison and baseline for NTL before and after the corridor, illustrating the changes in NTL that occurred prior to the road's completion in 2004. As seen in Figure 12, the latest map shows the NTL lights along the corridor in 2024, nearly 20 years after its completion. The map indicates an increase in the intensity and extent of NTL over time. More changes are found at the end of the corridor in Zambia and the DRC.

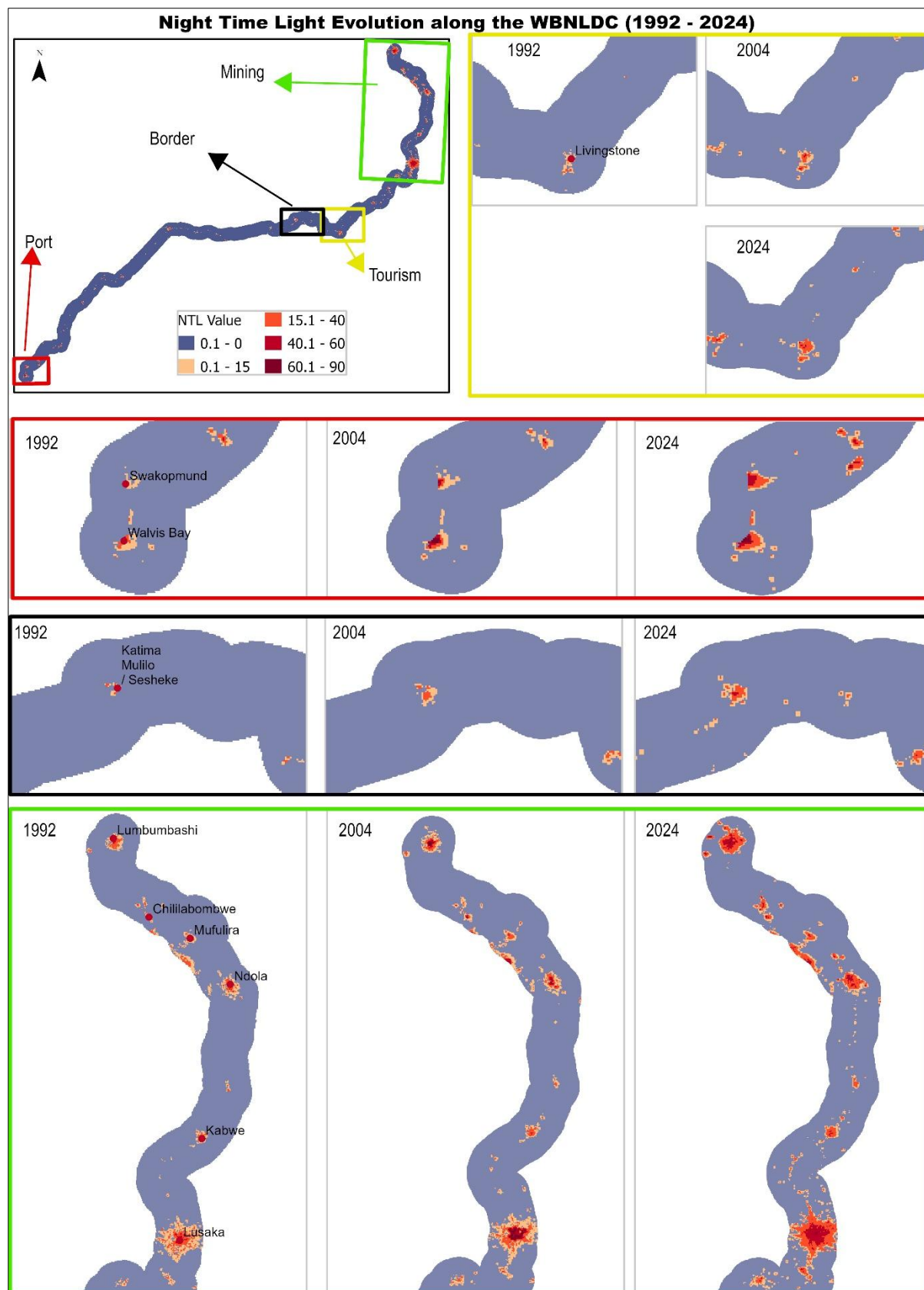


Figure 12: Spatial distribution of NTL along WBNLDC (1992 – 2024). Source: Authors' own design

5.3.1 Trend Analysis

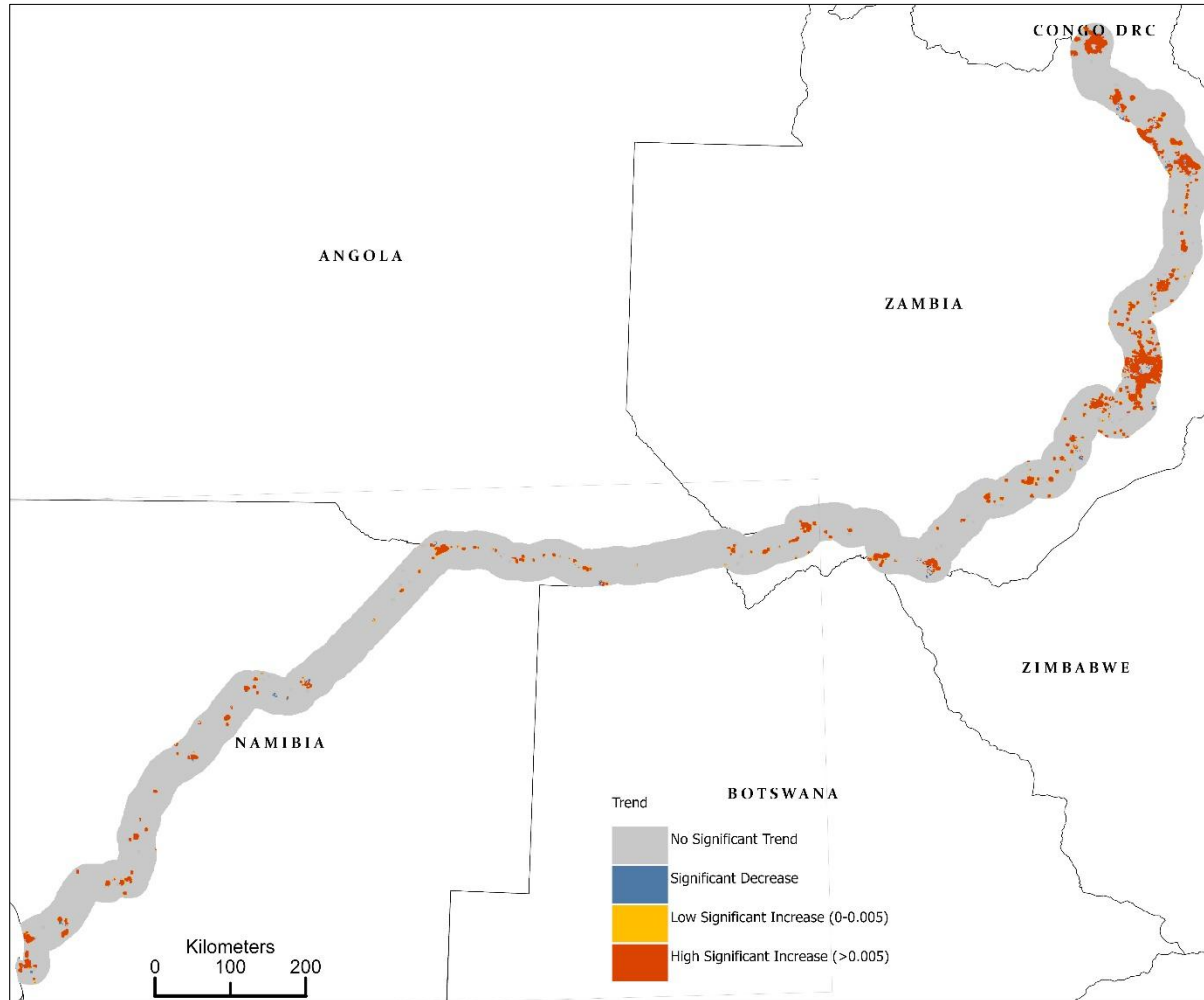


Figure 13: Trend Analysis (Theil Sen Slope and Mann-Kendall) along WBNLDC 2004 – 2024. Source: Authors' own design

Figure 13 shows the trend variation of NTL along the corridors since the completion of the corridor in 2004. The results show that the NTL patterns are heterogeneous from one side to another of the corridor. The evolving patterns have been classified into four levels of significance based on the Mann-Kendall and Theil-Sen slope values, indicating either a significantly increasing, decreasing or no trend. Most parts of the corridor have

remained unchanged over the years of corridor implementation, indicating no significant trend was detected; however, we can observe hotspots of increasing trends, which are most noticeable in Zambia and the DRC, especially in the northeastern part of the corridor. There are also some highly significant increases in Namibia; however, they are much smaller in extent compared to the northeastern part of the corridor.

5.3.2 Spatial DiD and Event Regression

Corridor level Analysis

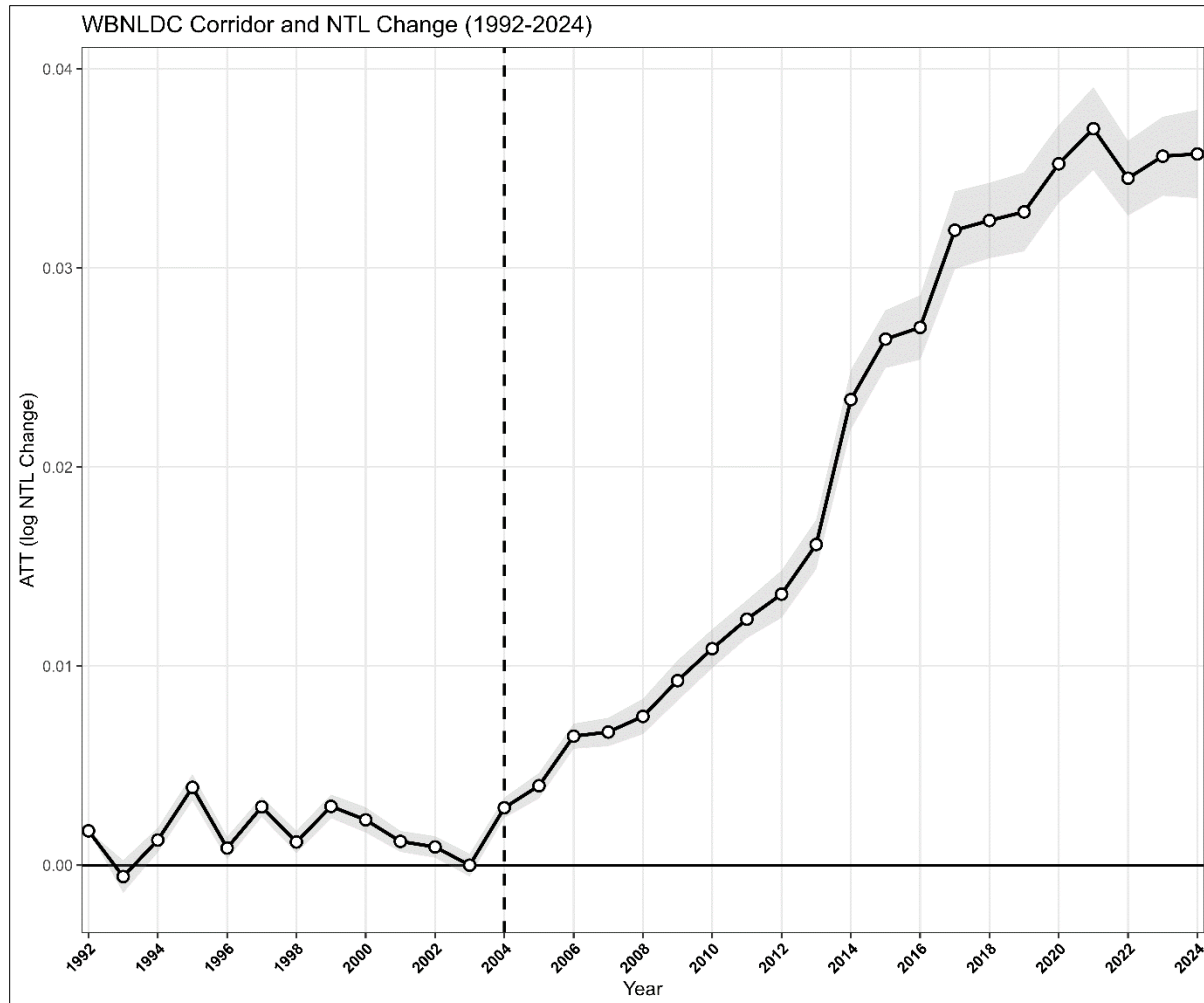


Figure 14: Overall corridor changes relative to the year before treatment. Source: Authors' own design

Figure 14 illustrates the overall changes in NTL along the WBNLDC from 1992 to 2024. By comparing 0-25km road proximity grids versus 30-100km control grids, we observe statistically stable and near-zero pre-trends for 12 years prior to treatment in 2004. This confirms the validity of the parallel trends assumption and indicates that the study area was not experiencing significant corridor-related growth before the official 2004

completion date. The complete regression coefficients, including point estimates and standard errors for each year in the 1992–2024 panel, are provided in Appendix A1.

The results indicate that few years after the treatment was applied, there is a gradual increase in NTL values, indicating a positive trend, which became more significant after 10 years, suggesting that the effect of the road took some time to materialise (Appendix A.4). This means that there is a lagged association of the corridor on economic growth.

These results were confirmed by the distance-decay analysis in Appendix A.2, which shows that economic activities are higher closer to the roads. The strongest magnitudes are found within 10km and after 25km the effects becomes much weaker.

Country-Level Heterogeneity Analysis

Figure 15 below shows that all countries have experienced a significant coefficient as indicated by increased NTL in all countries. The country-specific coefficient for Namibia, Zambia, and the DRC is detailed in Appendix Table A.5, confirming that the post-treatment divergence is robust across all three national segments. It is clear that there are visible differences in those positive increases from country to country. For instance, the DRC, mainly at Lumbumbashi, experienced the highest increase in NTL, which became much stronger as early as in year 2, indicating rapid acceleration and peaking to a 14 % increase by year 20 (2024). In contrast, Zambia and Namibia experience d more moderate increases of 4.7% and 1.2% respectively, by the same period.

However, the pre-treatment window (1992–2003) requires careful interpretation. While Namibia has statistically significant pre-treatment coefficients that are relatively small and closer to 0 the DRC and Zambia show minor instabilities, with coefficients reaching up to

0.008 (Appendix A.5). Although these pre-trends are relatively small, their presence suggests that some divergence between treated and control areas may have existed prior to 2004. This warrants a degree of caution; as infrastructure is often placed to serve anticipated extractive growth.

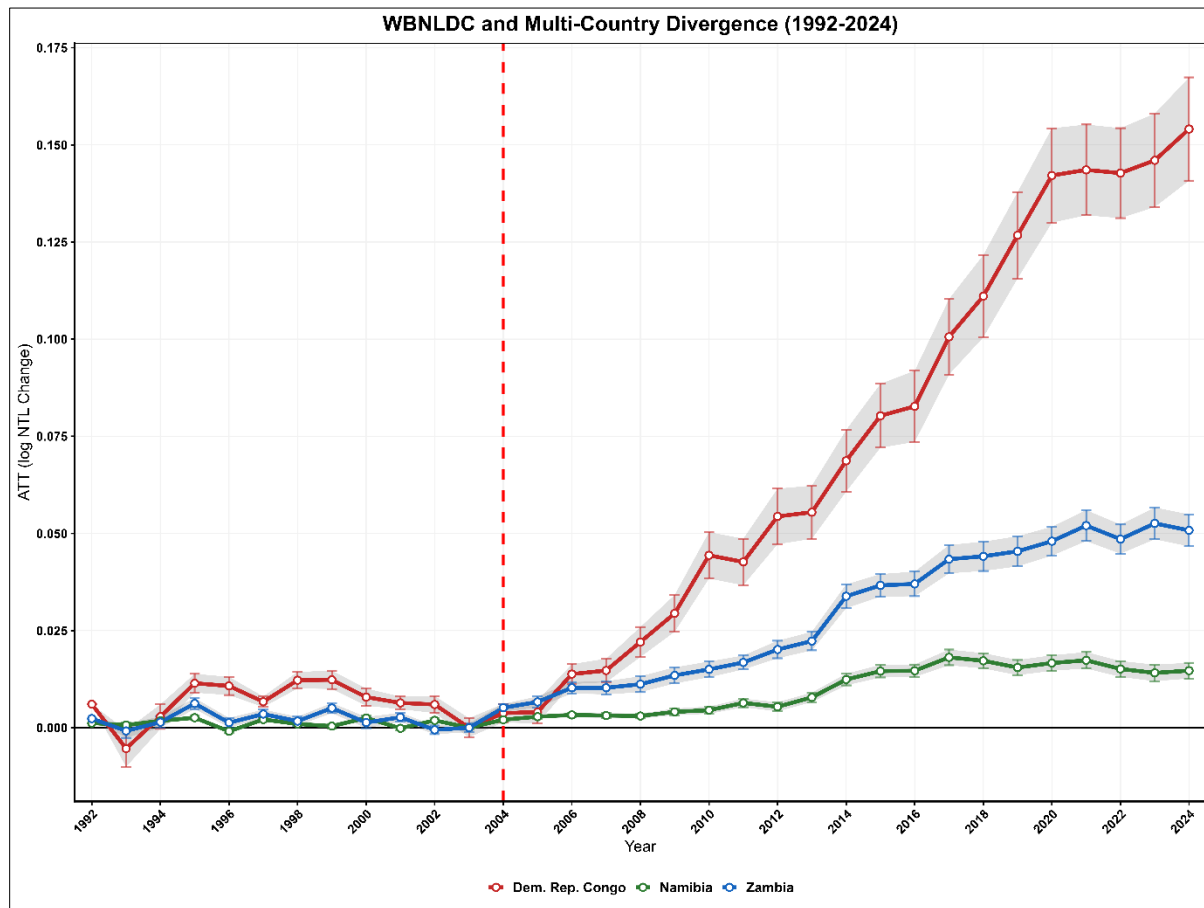


Figure 15: Nighttime lights country to country changes. Source: Authors' own design

Comparing NTL in selected cities along the WBNLDC

We selected cities along the corridor to allow for comparison. When it comes to the absolute increase in NTL at each town since the completion of the corridor, it is clear that Lusaka and Lubumbashi, as the largest cities in the entire corridor, had the highest

increase (Figure 16). Other notable cities with a significant increase in absolute NTL are Chililabombwe and Ndola, followed by Mufulira, all of which are mining towns. Swakopmund, Walvis Bay and Livingstone had similar NTL values over time. The absolute change in NTL across cities is not comparable in relation to corridor completion due to their different base levels and various economic activities. Therefore, the absolute values were normalised in Figure 16 to allow for comparisons.

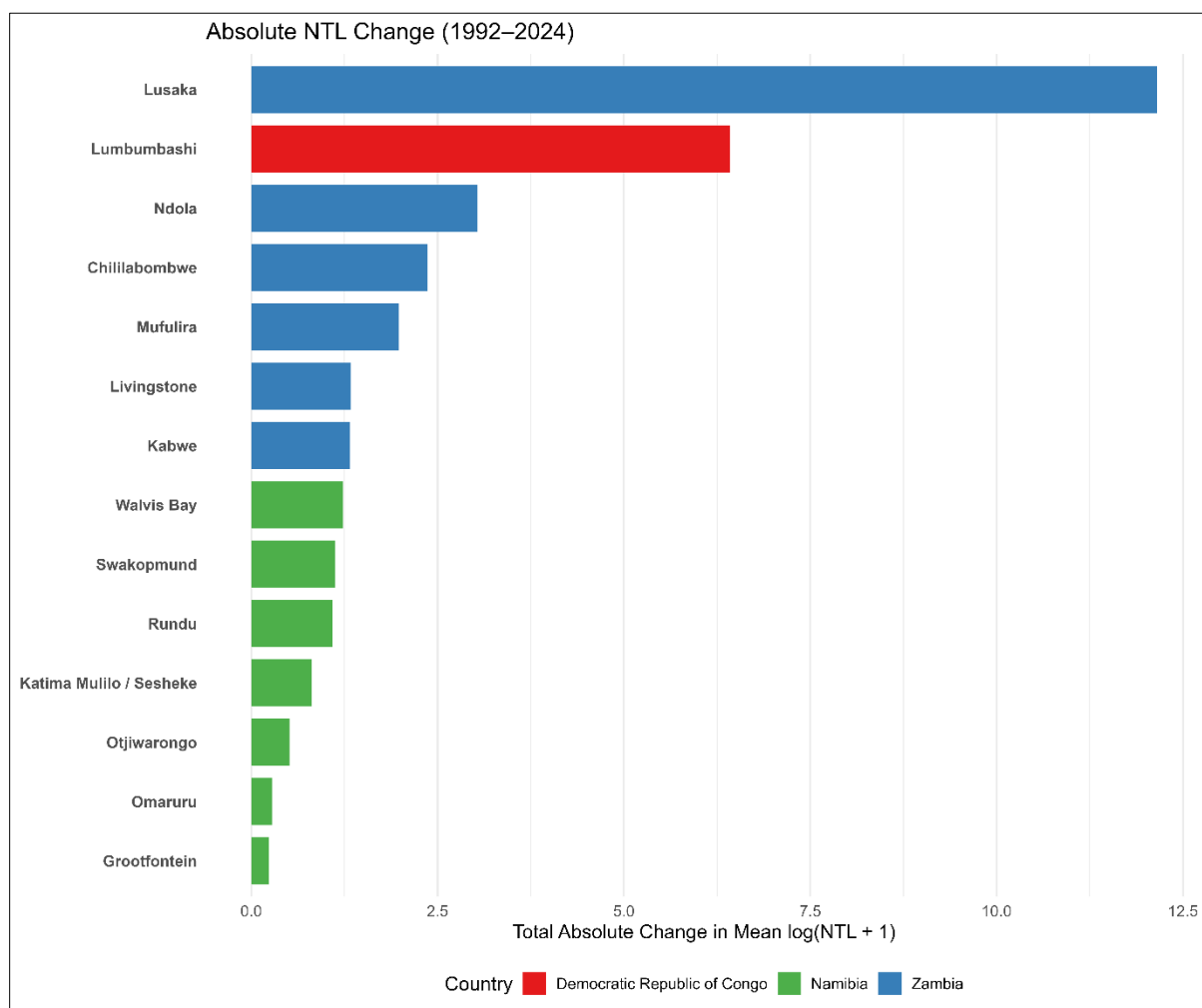


Figure 16: NTL changes of selected towns along the corridor. Source: Authors' own design

The relative growth trajectories of NTL across the fourteen corridor towns from 1992 to 2024 are presented in Figure 17. The results show that the corridor had heterogeneous associations across various towns and countries. We have normalised the NTL value to 2004, the year of treatment, to ensure city-to-city comparison without worrying about different base NTL values. Although we cannot entirely attribute the changes in NTL to the road completion given the lack of data on mining and electrification to rule out their effects, the overall pattern indicates significant increase in NTL across many towns relative to 2004. Towns such as Rundu, Omaruru, Swakopmund as well as the transit hub of Katima Mulilo / Sesheke, where luminosity levels have increased by over 140% relative to 2004 in Namibia. In Zambia, towns such as, Kabwe, Ndola, Mufulira, Sesheke and Livingstone also show a moderate increase in NTL since the completion of the corridor. Despite the observed increases in the towns mentioned, there is a significant difference in the values within each country, as well as in comparison to other countries. Lumbumbashi, of course, being the only town along the corridor in the DRC, had also experienced higher changes in NTL since the corridor's completion, which is more than 150% it was before the corridor was completed.

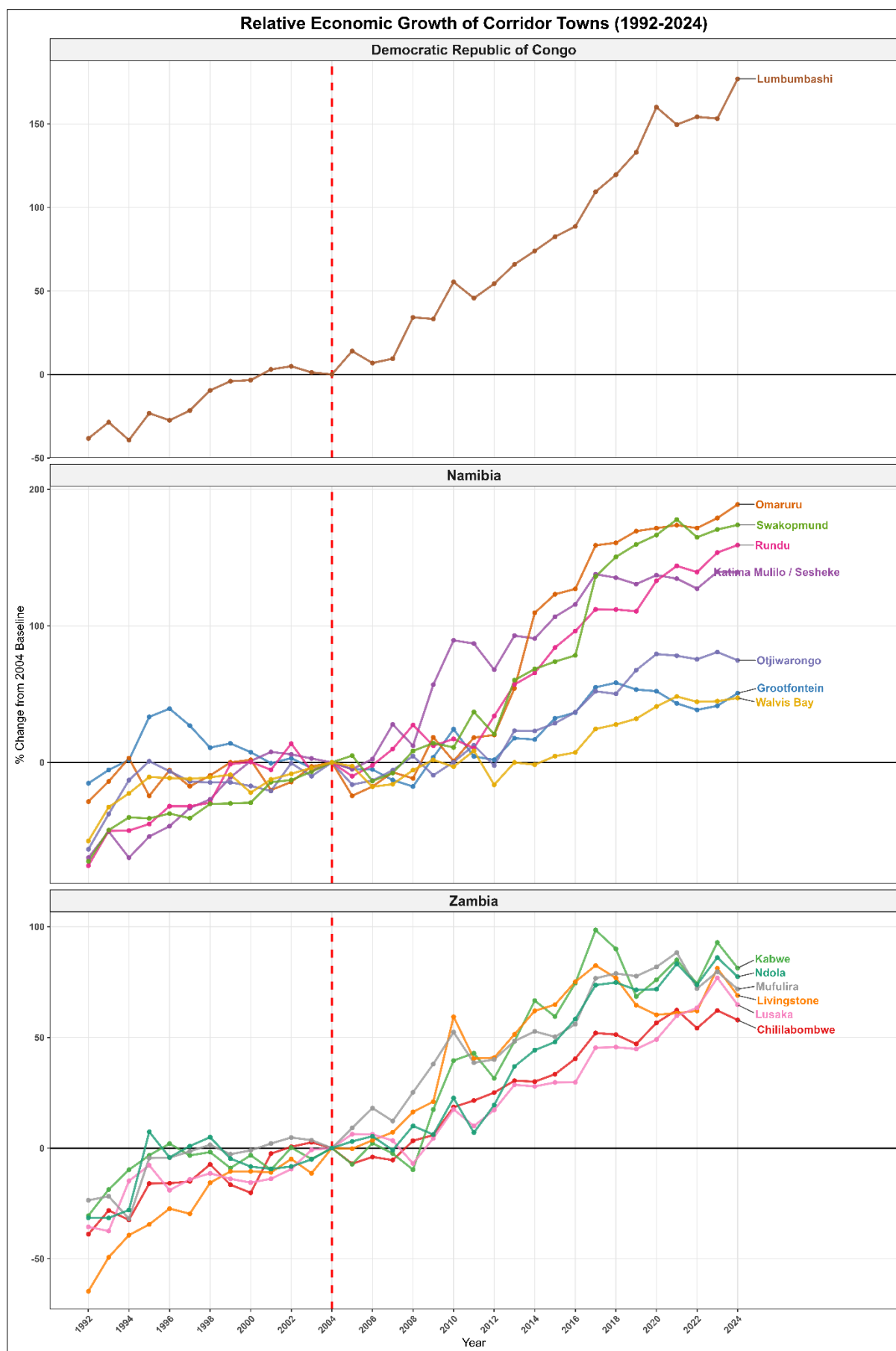


Figure 17: Town NTL time series percentage change by country, normalised to treatment year (2004). Source: Authors' own design

5.4 Discussion

Building on the conceptual framework developed in this paper, development corridors can shape regional development through different economic mechanisms. Scenario A describes a pathway in which improved connectivity stimulates integration and agglomeration, allowing economic activity to diffuse beyond major nodes into intermediate towns and surrounding rural areas. Scenario B instead characterises development corridors as infrastructures of circulation that selectively integrate strategic locations, such as extraction sites, logistics hubs, and major urban centres, into global economic networks while bypassing many intermediate regions (Enns, 2018; Dannenberg et al., 2018; Scholvin, 2021).

The empirical analysis of nighttime lights (NTL) along the Walvis Bay–Ndola–Lubumbashi Development Corridor (WBNLDC) allows us to assess which of these mechanisms is more consistent with the observed spatial patterns. While NTL intensity has increased along the corridor since its completion in 2004, the growth is uneven and concentrated in specific locations rather than diffusing across the corridor landscape. Importantly, our empirical strategy does not directly test the underlying political–economic mechanisms of corridor development. Instead, it evaluates whether the spatial patterns captured in nighttime lights data correspond more closely to the integration and agglomeration dynamics described in Scenario A or to the selective integration and enclave development patterns associated with Scenario B.

Overall, the observed spatial patterns align more closely with the latter mechanism. Increases in luminosity are concentrated in mining regions, major logistics nodes, and tourism hubs, while large intermediate sections of the corridor remain comparatively dark.

These findings suggest that the WBNLDC has primarily facilitated the selective integration of key locations into global commodity and tourism networks rather than generating corridor-wide economic transformation.

5.4.1 Mining and extraction as enclave-based integration

One of the most pronounced patterns observed in the nighttime lights analysis is the concentration of economic activity in mining towns in Zambia's Copperbelt and the Katanga region of the DRC, including Mufulira, Ndola, and Lubumbashi. These locations show strong increases in nighttime luminosity over time, indicating intensified economic activity closely linked to mineral extraction.

Zambia and the DRC are among Africa's largest copper producers, generating substantial export revenues through copper and cobalt production (Saggese et al., 2024). Rising global demand for these minerals during the early 2000s attracted significant investment to the region, driving the expansion of extraction and associated infrastructure. Mining operations and early-stage processing activities, such as the production of anodes, cathodes, and blisters, are spatially anchored near extraction sites, which helps explain the localised increases in nighttime lights observed in these towns (Saggese, Shawa and Wani, 2024; World Bank, 2024).

The corridor also plays an important logistical role in facilitating the movement of these commodities to international markets. Increased cargo traffic through border towns such as Katima Mulilo and Sesheke, as well as through the port of Walvis Bay, illustrates how extractive industries reshape development along the corridor (Nakale, 2023; Dlamini, 2025; Zambia Transport and Logistics, 2025). Much of the transported cargo consists of

copper and cobalt rather than diversified commodities, emphasising the corridor's role as a key export route integrated into global commodity markets (Namibian Ports Authority (NAMPORT), 2024; Zambia Transport and Logistics, 2025).

The rise in nighttime lights observed in these locations likely reflects the expansion of logistics services and supporting infrastructure, including retail outlets, fuel stations, housing, and border facilities required to sustain increasing cargo flows (Zeller, 2009; New Era, 2022). Similarly, the expansion of port facilities in Walvis Bay has strengthened its role as a regional gateway connecting Zambia and the DRC to international markets (Namibian Ports Authority (NAMPORT), 2019; Zajontz, 2024).

From the perspective of the conceptual framework developed in this paper, these patterns are consistent with Scenario B, where corridor infrastructure selectively integrates extraction sites and logistics hubs into global commodity networks. Rather than generating widespread industrial clustering along the corridor, economic activity remains concentrated in a limited number of nodes. The anticipated backward and forward linkages that might stimulate broader regional diversification appear limited.

Evidence from other mining regions reinforces this interpretation. In locations such as Kitwe and Solwezi, studies have shown that large-scale mining operations often coexist with relatively weak local supply networks and limited local value addition (Benshaul-Tolonen and Fernandez Musso, 2025; Schulz et al., 2019; Kesselring, 2025). Although the mining sector generates substantial export revenues, it employs only a small share of the workforce, underscoring the limited inclusiveness of extractive-led growth (Ministry of Mines and Mineral Development, 2024). These dynamics illustrate how extractive

industries can generate localised economic activity without necessarily fostering broader structural transformation.

Taken together, the spatial concentration of nighttime light growth in mining regions and logistics hubs suggests that the WBNLDC primarily supports the circulation of extractive commodities rather than producing widespread economic integration along the corridor

5.4.2 Tourism as Enclave-based Integration

In addition to mining regions, significant increases in nighttime light intensity are observed in major tourism destinations along the corridor, particularly Livingstone/Victoria Falls and Swakopmund. These locations illustrate another pathway through which corridor connectivity can reinforce spatially concentrated economic development. Similar to mining nodes, tourism hubs represent locations where economic activity clusters around specific assets and infrastructures, creating localised agglomerations that remain weakly connected to surrounding regions.

Livingstone and Victoria Falls have experienced sustained growth in international tourism over recent decades. The Zambian government has actively promoted tourism as part of a broader strategy to diversify the national economy away from copper dependence (McLachlan and Binns, 2014). As a gateway to the Kavango–Zambezi (KAZA) Transfrontier Conservation Area, the region attracts substantial tourist flows and supports a wide range of tourism-related services, including accommodation, transportation, and guided tours (Mlilo et al., 2024b). Research highlights how towns such as Victoria Falls and Livingstone have become important service hubs within regional tourism networks, providing infrastructure and services for visitors to surrounding natural attractions.

Tourism has become an increasingly important economic sector in the region. For example, tourism revenue associated with Victoria Falls accounts for a substantial share of Zimbabwe's national economy and exceeded USD 1 billion by 2020 (Mlilo et al., 2024a). The expansion of hotels, restaurants, tour services, and related infrastructure required to support international tourism likely contributes to the increases in nighttime lights observed in these locations.

A similar pattern is observed in Swakopmund, one of Namibia's most prominent tourism destinations. Located between the Atlantic Ocean and the Namib Desert, Swakopmund offers a diverse range of tourism activities, including adventure tourism such as sandboarding and desert excursions (Nyaungwa, 2024). The town's historical legacy and distinctive cultural landscape have further strengthened its tourism appeal (Amutenja, 2025). As tourism has expanded, investments in hospitality infrastructure, retail services, and transport facilities have contributed to increasing economic activity in the area.

While tourism development generates significant economic activity in these destinations, it remains spatially concentrated in a limited number of locations with strong natural, cultural, or historical advantages. Similar to mining regions, tourism-related growth tends to cluster in established hubs rather than spreading evenly across surrounding rural areas. As a result, tourism may reinforce localised agglomeration dynamics without necessarily generating broader corridor-wide development.

From the perspective of the conceptual framework developed in this paper, these patterns can also be interpreted as a form of enclave-based integration. Tourism activities capitalise on specific natural and cultural assets and generate economic opportunities primarily in those locations where such assets are present. The resulting economic

growth is therefore concentrated in destination nodes such as Livingstone/Victoria Falls and Swakopmund, while intermediate regions along the corridor remain only weakly integrated into tourism value chains.

The spatial patterns observed in nighttime lights along the corridor reflect these dynamics. Increases in luminosity are most visible in tourism hubs, while surrounding areas show comparatively limited change. This suggests that, similar to mining activities, tourism development along the WBNLDC contributes to a pattern of selective integration in which corridor accessibility strengthens economic activity in a limited number of strategically located nodes rather than producing widespread spatial diffusion.

5.4.3 Structural Dynamics Shaping Corridor Development Patterns

Despite localised growth in mining and tourism hubs, large sections of the corridor, particularly in Namibia, remain relatively dark in nighttime light observations. The corridor was originally expected to attract investment in sectors such as agriculture, manufacturing, and tourism. However, these expectations have not fully materialised, and economic activity remains concentrated in a limited number of locations. Understanding these patterns requires considering both context-specific factors and the broader political–economic dynamics shaping corridor development.

Several structural conditions help explain why intermediate areas along the WBNLDC have experienced limited economic activity despite improved connectivity. One important factor is the persistence of sectoral investment patterns dominated by extractive industries. In both Namibia and Zambia, FDI remains heavily concentrated in mining and resource-related activities, making it difficult to attract investment into manufacturing,

agriculture, or other forms of productive diversification. Under these conditions, corridor infrastructure primarily facilitates the circulation of commodities between extraction sites, logistics hubs, and international markets rather than stimulating diversified regional development.

Land use dynamics along the corridor also shape development patterns. Large sections of the corridor in Namibia pass through regions characterised by multiple and sometimes competing land uses, including national parks, community conservancies, forests, and agricultural land. In particular, the corridor intersects with the Kavango–Zambezi Transfrontier Conservation Area (KAZA), the largest transboundary conservation area in Southern Africa. This region prioritises biodiversity protection and wildlife mobility across Namibia, Botswana, Zambia, Zimbabwe, and Angola. While these environmental assets generate significant ecological and tourism value, they can also create tensions with agricultural expansion and industrial development.

Human-wildlife conflict illustrates how these land use dynamics affect economic activity along the corridor. In northeastern Namibia and other central parts of the corridor, wildlife movement and crop damage often discourage agricultural investment. These areas contain some of Namibia's most fertile land, yet the risks associated with wildlife interactions can reduce incentives for farming and agro-processing activities. As a result, many of these areas remain transit zones rather than locations where substantial value is created.

Conflicts between conservation objectives and development initiatives further illustrate these challenges. For example, the allocation of land for large-scale agricultural schemes

under Namibia's Green Scheme programme has generated disputes between government ministries responsible for agriculture and environmental conservation. In 2017, the Ministry of Agriculture, Water and Forestry allocated land in the Zambezi State Forest for agricultural development, prompting objections from the Ministry of Environment and Tourism, which argued that the area forms part of a wildlife corridor within the KAZA conservation system (Grobler, 2017; Dittman, 2025). Such institutional tensions can create uncertainty for investors and complicate long-term development planning.

Even where agricultural projects have been implemented, outcomes have often been mixed. The Kalimbeza irrigation project in Namibia's Zambezi Region initially raised expectations for agricultural development and improved food security. However, production levels declined significantly between 2016 and 2022, reflecting challenges related to flooding, infrastructure constraints, and management capacity (Republic of Namibia, 2022). Similar issues, including limited skills, inadequate market access, corruption, and logistical constraints; have affected other Green Scheme projects in the Zambezi, Kavango West, and Kavango East regions (Lamprecht, 2024; Josef, 2025). In some cases, agricultural production has also been affected by delays in processing due to limited milling capacity concentrated in major cities. While these examples highlight local development challenges, they also reflect broader structural dynamics emphasised in Scenario B. Development corridors are often designed primarily to facilitate the circulation of commodities between production zones and global markets. Under such conditions, infrastructure investment and economic activity tend to concentrate in strategically important nodes such as mines, border crossings, and ports; while

intermediate regions remain only weakly integrated into corridor-based economic networks (Dannenberg et al., 2018; Lesutis, 2019; Scholvin, 2021).

The spatial patterns observed along the WBNLDC appear consistent with this interpretation. Rather than generating evenly distributed development across the corridor landscape, the corridor selectively connects key resource extraction zones and logistics hubs to international markets while leaving many intermediate areas with limited economic activity. In this sense, the persistence of dark areas in nighttime lights observations does not necessarily indicate a failure of corridor infrastructure but may reflect the underlying structural logic through which corridor-led development unfolds.

5.4.4 Interpreting Corridor Development Patterns and Theoretical Contribution

Taken together, the empirical evidence suggests that the WBNLDC has contributed to economic activity along its route but in a highly uneven spatial manner. Growth in nighttime lights is concentrated in mining regions, logistics nodes, and tourism hubs, while large sections of the corridor remain comparatively dark. These spatial patterns indicate that improved connectivity has not translated into widespread economic distribution along the corridor.

Within the conceptual framework developed in this paper, these results align more closely with the selective integration dynamics described in Scenario B than with the corridor-wide integration and agglomeration pathway outlined in Scenario A. Rather than generating evenly distributed development across corridor regions, the WBNLDC appears to function primarily as an infrastructure facilitating the circulation of commodities and tourists between strategically important locations. In this sense, the observed spatial

outcomes reflect the selective territorial integration of mining regions, logistics hubs, and tourism destinations into global economic networks (Enns, 2018; Dannenberg et al., 2018; Scholvin, 2021).

At the same time, these findings must be interpreted with caution given the limitations of nighttime lights data. NTL captures electrification, infrastructure expansion, and built-up economic activity rather than broader indicators of inclusive development such as employment quality, income distribution, or local value creation (Henderson et al., 2011; Gibson, 2021). Increases in luminosity may therefore reflect capital-intensive activities such as mining operations, logistics facilities, or port infrastructure that generate limited local spillovers. Furthermore, the empirical analysis cannot fully disentangle the effects of corridor infrastructure from other factors such as global commodity cycles, tourism investments, or electrification programmes. The results should therefore be interpreted as identifying spatial patterns associated with corridor proximity rather than establishing definitive causal effects.

Beyond the empirical findings, this study contributes to the literature on development corridors and infrastructure-led development in three ways. First, it advances the conceptualisation of development corridors as politically and economically embedded infrastructures that reshape spatial development through mechanisms of capital circulation and territorial integration rather than as neutral transport investments (Enns, 2018; Dannenberg et al., 2018; Scholvin, 2021). Second, by distinguishing between the mechanisms of integration and agglomeration (Scenario A) and selective integration and extractive enclaves (Scenario B), the paper provides a framework for interpreting uneven spatial outcomes as potentially inherent to corridor-led development rather than as

deviations from intended policy goals. Third, the study demonstrates how harmonised nighttime lights data combined with spatial quasi-experimental methods can help identify spatial development signatures associated with different corridor development mechanisms.

5.5 Conclusion

This paper examined the spatial development patterns of the Walvis Bay–Ndola–Lubumbashi Development Corridor (WBNLDC) using harmonized nighttime lights data between 1992 and 2024. By combining spatial trend analysis with a spatial difference-in-differences event-study framework, the study assessed how economic activity has evolved along the corridor since its completion in 2004 and evaluated whether these changes correspond more closely to corridor-wide integration and agglomeration dynamics or to patterns of selective integration.

The results show that economic activity along the corridor has increased over time, as reflected in rising nighttime luminosity. However, this growth is highly uneven. The most pronounced increases are concentrated in mining towns in Zambia and the Democratic Republic of Congo, in logistics hubs such as border crossings and the port of Walvis Bay, and in tourism destinations such as Livingstone and Swakopmund. In contrast, large intermediate sections of the corridor show little change in nighttime lights intensity, indicating limited diffusion of economic activity into surrounding rural regions.

These findings suggest that the WBNLDC has primarily facilitated the selective integration of resource rich regions and strategic nodes into global economic networks rather than generating corridor-wide economic transformation. While improved connectivity has strengthened logistical linkages between extraction sites, transport hubs, and international markets, the expected diffusion of economic activity along the corridor has remained limited. In this sense, the spatial patterns observed along the WBNLDC are more consistent with the selective integration dynamics described in Scenario B than with the broader integration and agglomeration pathway associated with Scenario A

From a policy perspective, the findings highlight the limits of infrastructure investment alone as a driver of balanced regional development. Development corridors can significantly improve connectivity and facilitate trade, but without complementary investments in productive capacity, governance coordination, and economic diversification, their benefits may remain concentrated in a limited number of locations. Achieving more inclusive development outcomes along corridors such as the WBNLDC may therefore require policies that strengthen local supply chains, support regional industries, and improve coordination among national and regional stakeholders.

Future research could build on this study by integrating nighttime lights data with additional datasets on mining activities, electrification programs, firm dynamics, and household level development indicators. Such approaches would allow researchers to better understand how corridor infrastructure interacts with local economies and institutions to shape development outcomes. Comparative studies across multiple African development corridors could also help determine whether the spatial patterns observed along the WBNLDC represent broader dynamics of corridor-led development on the continent.

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Data availability statement

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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6 Infrastructural Assemblages and Uneven Livelihoods: Roads, Corridors and Conservancies in Rural Namibia

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Abstract

Infrastructure is widely promoted as a driver of rural development, yet most research examines individual infrastructure independently, focusing on individual systems such as dams, pipeline, roads or development corridors. This paper advances this literature by conceptualising infrastructure as an infrastructural assemblage: a configuration of coexisting systems with distinct spatial logics whose interactions shape access to economic opportunities and livelihood pathways. We examine development corridors, regional and district roads, and communal conservancies in Namibia's Zambezi Region. Using two waves of household survey data (2019 and 2023), combined with spatial measures of proximity and a Mundlak hybrid panel approach, we analyse how these infrastructures jointly relate to income, assets, land and social capital across different livelihood strategies. The findings show that infrastructural assemblages produce uneven development through three mechanisms. First, infrastructures embody competing spatial logics: district roads support local asset accumulation, while development corridors primarily benefit better-off households. Second, infrastructure effects are mediated by household capabilities, shaping differentiated livelihood pathways. Third, the interactions between infrastructures do not always reinforce one another district roads may promote agricultural diversification, but when running through communal conservancies that restrict land use and prioritise conservation, this interaction may induce trade-offs, such as land use competition leading to human-wildlife conflict rather than complementary gains. The paper demonstrates how interacting infrastructural assemblages and household capabilities jointly produce uneven and socially differentiated rural transformation. This paper contributes to current debates on economic geography by

providing a joint, place-based analysis of overlapping infrastructural logics and their uneven livelihood outcome.

Keywords

Infrastructural assemblage, regional development, communal conservancies, uneven development,

6.1 Introduction

Infrastructure development is widely regarded as a fundamental strategy for reducing regional disparities and eradicating poverty in many developing regions, particularly in the Global South (Aggarwal, 2018; Gateri & K'Akumu, 2023; Rehman et al., 2023). This consensus has driven significant investment by governments and multilateral organisations into multiple mega projects, including hard infrastructure (such as development corridors, highways, and rural roads) (Calderón & Servén, 2004; Gateri & K'Akumu, 2023; Ghosal, 2013; Schindler & Kanai, 2021). Beyond physical connectivity, scholarship recognises the importance of soft infrastructure in rural development (Ghosal, 2013). Soft infrastructure refers to institutions, organisations and governance frameworks that are in place to support the functioning of social and economic systems. In rural Africa, this prominently includes Community-Based Natural Resource Management (CBNRM) programs which functions as environmental infrastructure such as communal conservancies, introduced in rural areas to combine the conservation efforts with rural livelihoods improvement and poverty eradication (Bollig & Krause, 2023; Bollig & Vehrs, 2021; Fuseini, 2024; Ghosal, 2013). Unlike hard infrastructure that provides physical connectivity to markets, communal conservancies function as institutional connectivity / governance that links marginalised landscapes to tourism-oriented global value chains (Kalvelage et al., 2021). Through formalised networks and collective governance arrangements, this environmental infrastructure channel resources, organise decision-making and enable economic opportunities for local populations (Fuseini, 2024; Kalvelage et al., 2021; Kioko & Changwony, 2025).

However, rural spaces are increasingly defined by competing infrastructural logics (Kioko & Changwony, 2025). While scholarship typically studies infrastructures independently of one another (Hudalah, 2026), this paper draws on the assemblage theory (DeLanda, 2006; Deleuze & Guattari, 1987) to conceptualise this overlap. Assemblage refers to multiple configurations of heterogeneous materials (human and non-human) that coexist within and across different layers of reality, shaping relations and functions (Paulos, 2024). Drawing on the relational turn in development studies, which emphasizes the socio-material agency of assemblages and networks (Natarajan et al., 2022), we

conceptualise infrastructure as a set of interconnected systems to together make up an infrastructural assemblage. Foundational literature demonstrated that infrastructure is not just physical object but are complex socio-material assemblages that create networks, institutions, and human practices (Larkin, 2013; Star, 1999). Similarly, recent scholarship conceptualises large-scale mega-projects, such as development and urban corridors, as assemblages that are continuously territorialised and contested by multiple actors (Hudalah, 2026). However, these recent contributions remain primarily theoretical and conceptual, thus scholars have explicitly called for grounded empirical investigations into how these assemblages manifest in reality (Hudalah, 2026). In addition, there is a call to recognize the activities and subjective experiences of individual citizens and to adopt place-based, whole-system approaches to regional development (Willett, 2023). We advance this literature in two ways: First, we transition from theoretical to empirical application by applying this framework to assess actual place-based livelihood outcomes. Second, we expand this thinking beyond large-scale mega-projects to consider what occurs in rural peripheries where hard infrastructure overlaps with existing soft institutional infrastructure. How do overlapping hard and soft infrastructures, mediated by household capabilities, shape differentiated livelihood pathways in the Zambezi Region? Therefore, we conceptualise infrastructural assemblage as a complex configuration of coexisting systems of hard infrastructure and soft infrastructure.

Within this assemblage, each component produces differentiated outcomes. Hard infrastructure for instance such as development corridors control the movement of resources and humans (Dannenberg et al., 2018), often creating tensions between value extraction and local value capture (Gansauer et al., 2024). Similarly, soft infrastructure such as communal conservancies are often characterised by institutional bricolage rather than seamless governance (Kadhikwa et al., 2026), generating local conflicts and exposing communities to human-wildlife conflict (Carpenter, 2024). Lastly, household capabilities are an important mediating factor that condition how households can use, avoid or are constrained by the assemblage and whether access can be converted into tangible livelihood gains. However, the spatial intersection of these assemblages could also create deeper structural clash due to their conflicting scopes. For instance, while regional roads may provide physical access to new markets, the overlapping communal

conservancy may strictly restrict the agricultural land-use required to benefit from reduced transport costs and increased market access (Kadhikwa et al., 2026). Furthermore, development corridors may provide market connectivity, yet rural populations may still fail to benefit if they lack the capabilities needed to participate (Asher & Novosad, 2020; Gautam et al., 2025). At the same time, the benefits of community-based soft infrastructure are frequently captured by specific local elites (Vehrs et al., 2022). Together, these dynamics highlight that infrastructure-driven development is neither automatic nor inherently inclusive; rather, infrastructural assemblages dynamically produce uneven development.

Despite these insights, existing scholarship exhibits two key limitations. First, existing scholarship tends to analyse these infrastructures independently (Zheng, 2025), paying limited attention to the complex nature of rural economies where hard transport infrastructure and soft infrastructure are increasingly becoming popular and often interact. Second, most studies measure infrastructural outcomes in terms of aggregated economic outcomes such as trade flows and total value generated (Rehman et al., 2023; Wiegand et al., 2023). While useful, these macro-level metrics assume that infrastructure automatically and uniformly benefits all populations, thereby masking how benefits are unevenly distributed and the mediating role of capabilities (Willett, 2023). This limits our understanding on how overlapping infrastructure shape household livelihoods (Khandker et al., 2006; Kingombe, 2011).

This paper addresses those gaps by using an infrastructural assemblage approach consisting of development corridors, regional roads and communal conservancies. This assemblage interacts with household capabilities to produce differentiated livelihood pathways. The study focuses on the Zambezi Region of Namibia, which offers an ideal setting where this infrastructural assemblage exists. The region is located at the centre of the Kavango–Zambezi Transfrontier Conservation Area (KAZA TFCA) and has more than half of the area under conservation (Hulke et al., 2021; Mlilo et al., 2024). The region also hosts one of Namibia’s most important development initiative, the Walvis Bay–Ndola–Lubumbashi Development Corridor (WBNLDC) which aims to foster regional integration and transform the Zambezi Region into a logistics and food hub. (Dannenberg

et al., 2018; Kalvelage, Revilla Diez, et al., 2021). In summary, in terms of the assemblage the region has regional roads, including main and district roads, that connect local populations to regional markets while the development corridor and communal conservancies connect the region to broader global markets and value-chains. However, the region continues to be faced with a high level of poverty and unemployment (Namibia Statistics Agency (NSA), 2021). This overlapping landscape provides an ideal setting to examine how development and conservation initiatives interact to shape livelihoods.

This paper uses panel data from the household survey conducted in 2019 and 2023 from Zambezi region, together with spatial travel-time measures, conservancy location and transition models to analyse how infrastructural assemblage is associated with differentiated livelihood outcomes. Specifically, we examine how proximity to these overlapping infrastructures are associated with key household livelihood indicators such as income, assets, and social income. Drawing on the relational and processual dynamics of infrastructural assemblage (Hudalah, 2026), we explore how communal conservancies, development corridors and district roads interact with household capabilities to shape the livelihoods pathways in rural area.

The rest of the paper is structured as follows: Section 2 reviews literature on infrastructure and livelihood development and presents the pathways for infrastructure led development. Section 3 describes the case study and methodology followed to understand proximity to infrastructure and livelihoods. Section 4 presents the empirical results. Section 5 discusses these findings, and Section 6 concludes the results found in this paper.

6.2 Theoretical and Conceptual framing

Infrastructure plays a central role in shaping livelihoods and economic development by reducing transaction costs, connecting regions to markets, and facilitating the flow of goods, services, and people (Agénor, 2010; Calderón & Servén, 2004; Zheng, 2025). Yet their benefits are highly context dependent, unevenly distributed and can sometimes lead to further socio-economic trade-offs (Lesutis, 2019; Pokharel et al., 2023). Different types of infrastructures often coexist in the same locations, yet the literature frequently examines them separately, completely missing their interacting outcomes (Kioko & Changwony, 2025). Hard infrastructure such as development corridors and roads promote physical connectivity meanwhile soft infrastructure such as communal conservancies promote institutional connectivity. Although both aims to promote regional development and connectivity, they employ different spatial and institutional logics (Fuseini, 2024; Kioko & Changwony, 2025). We therefore treat conservancies as soft infrastructure, development corridors and regional roads as an infrastructural assemblage that shapes regional development differently. This paper aims to contribute to current debates in economic geography by examining how infrastructural assemblage shapes uneven development, territorial governance and spatial selectivity (Schindler & Kanai, 2021).

While extensive research exists on the developmental impacts of development corridors, regional roads, and conservancies when studied individually, a major gap remains in understanding their combined effects. Development corridors are often promoted as a driver for economic development through enabling manufacturing, agricultural commercialisation and intensification (Mulenga, 2013). However, such infrastructure can create concentration of growth in specific hubs and produce uneven distribution of economic outcomes (Dannenberg et al., 2018; Lesutis, 2019). In contrast, regional roads are often framed as more aligned with inclusive rural development because they connect rural areas to local markets and reduce transport costs, yet they do not automatically guarantee economic growth and poverty reduction (Fan & Chan-Kang, 2005). At the same time conservancies are increasingly becoming popular as a means for rural economic development for local population (Silva & Mosimane, 2013). In communal

areas, they often overlap with existing governing institutions such as traditional authorities, creating institutional clash which leads to conflict over land use zoning, or resources access and distribution and in some cases leads to creation of elite captures and further inequalities (Hulke et al., 2021; Kadhikwa et al., 2026).

This suggest that the overlapping systems are characterised by inherent limitations but also by complementary logics that can create both synergies and tensions (Gargallo, 2020; Hulke et al., 2021). Therefore, to capture the complex realities of rural development, this paper draws on assemblage theory (DeLanda, 2006; Deleuze & Guattari, 1987) to conceptualise this overlapping infrastructure of soft and hard infrastructure as an infrastructural assemblage where infrastructure frequently overlap and sometimes represent conflicting developmental agendas. Hard and soft infrastructure may sometimes complement one another; for example, regional roads may provide access to conservation areas, while development corridors may provide communal conservancies access to tourism global value chains. At the same time, development corridors and regional roads may facilitate agricultural intensification and commercialization, while communal conservancies prioritise conservation, which can lead to struggles over land use zoning and human-wildlife conflict. This structural clash may generate direct conflict on the ground, such as human-wildlife conflicts, where wildlife compete with people for resources and destroy agricultural assets, ultimately leading to livelihood losses (Kalvelage et al., 2021; Meyer & Börner, 2022). This reflects how infrastructural assemblages can produce spatial selectivity: access to opportunities is territorially regulated and may generate winners and losers across places and livelihood groups (Changwony et al., 2022; Jones, 1997)

To navigate the infrastructural assemblage and its conflicting agendas, the outcomes remain depended on the mediating role of household capabilities to unlock its full potential. Therefore, we challenge the belief that the mere presence of this infrastructural assembly will automatically lead to poverty reduction (Starkey & Hine, 2014). Although infrastructure reduces spatial friction and connects the population to the markets, its benefits remain limited without the mediating role of household capabilities such as education and assets. For instance, development corridors may bypass local population

if they lack the financial or human capital to participate in global value chains (Bignoli et al., 2024). Similarly, while rural roads can support labour movement out of subsistence agriculture (Asher & Novosad, 2020), this is highly dependent on households having the necessary skills to secure employment outside of the agriculture sector (Mutsami et al., 2025). Similarly, while communal conservancies are expected to connect the local population to the global value chains, meaningful employment is often reserved for those with formal training (Vehrs et al., 2022). Therefore, households' capabilities make an important mediating layer that determines whether the infrastructural access can be converted into tangible livelihood gains. Ultimately, this means that infrastructure-led development is mediated by the household capabilities such as education, labour stock, vehicle ownership, assets and social networks that determine how households might adapt to the infrastructural assemblage to move into differentiated livelihood pathways.

Drawing on Dorward et al, (2009), we categorise households into three dynamic livelihood typologies based on their livelihood strategy: Hanging in, Stepping Up and Stepping Out. Livelihood strategy refers to the activities that households are engaged in to secure income and sustain their livelihoods in a changing time shaped by structural conditions and institutional settings. In rural settings where agriculture remains central, these typologies provide a useful way to understand how households respond to infrastructural assemblages (Department for International Development (DFID), 2015). These typologies / transitions are based on how the households adapt to the assemblage shaped by their capabilities. The typologies refer to household livelihood status in each year, while transitions describe movement between these statuses from 2019 to 2023. 1) Hanging in / subsistence refers to when households are holding to their current livelihood activities to maintain the current lifestyle. These households may be constrained by capabilities, such as skills and low human capital or restricted land use zoning that limits intensification, to take advantage of the infrastructural assemblage. 2) Stepping up / Farm-market refers to households that expand or intensify their existing activities for income generation purposes. This may include the commercialisation of crops or livestock. Households in this category often have better capabilities, such as education and assets, such as vehicles and access to land for expansion and transport to markets.

3) Stepping out / Non-Farm Diversified involves households that shift away from traditional farming activities into a more diversified livelihood. This means that looking for employment opportunities outside of farming, in either formal, non-formal or business activities. These households may have higher education, better access to employment opportunities that allow them to diversify beyond agriculture.

Based on the gaps identified, this paper proposes a conceptual framework (Figure 18) that treats regional development and rural livelihoods as shaped by interdependent and interacting factors of infrastructure and individual household capabilities as an assemblage. The framework moves beyond a single mode of infrastructure to explore how hard infrastructure and soft infrastructure interact with human capabilities to shape livelihood outcomes. This framework recognises that household pathways within this assembly may also be shaped by broader issues such as social norms, environmental shocks, local institutional and socio-political context, such as land rights, leadership, and existing inequalities, that play a role in shaping how households make use of infrastructure access (Ghosal, 2013; Jones et al., 2015).

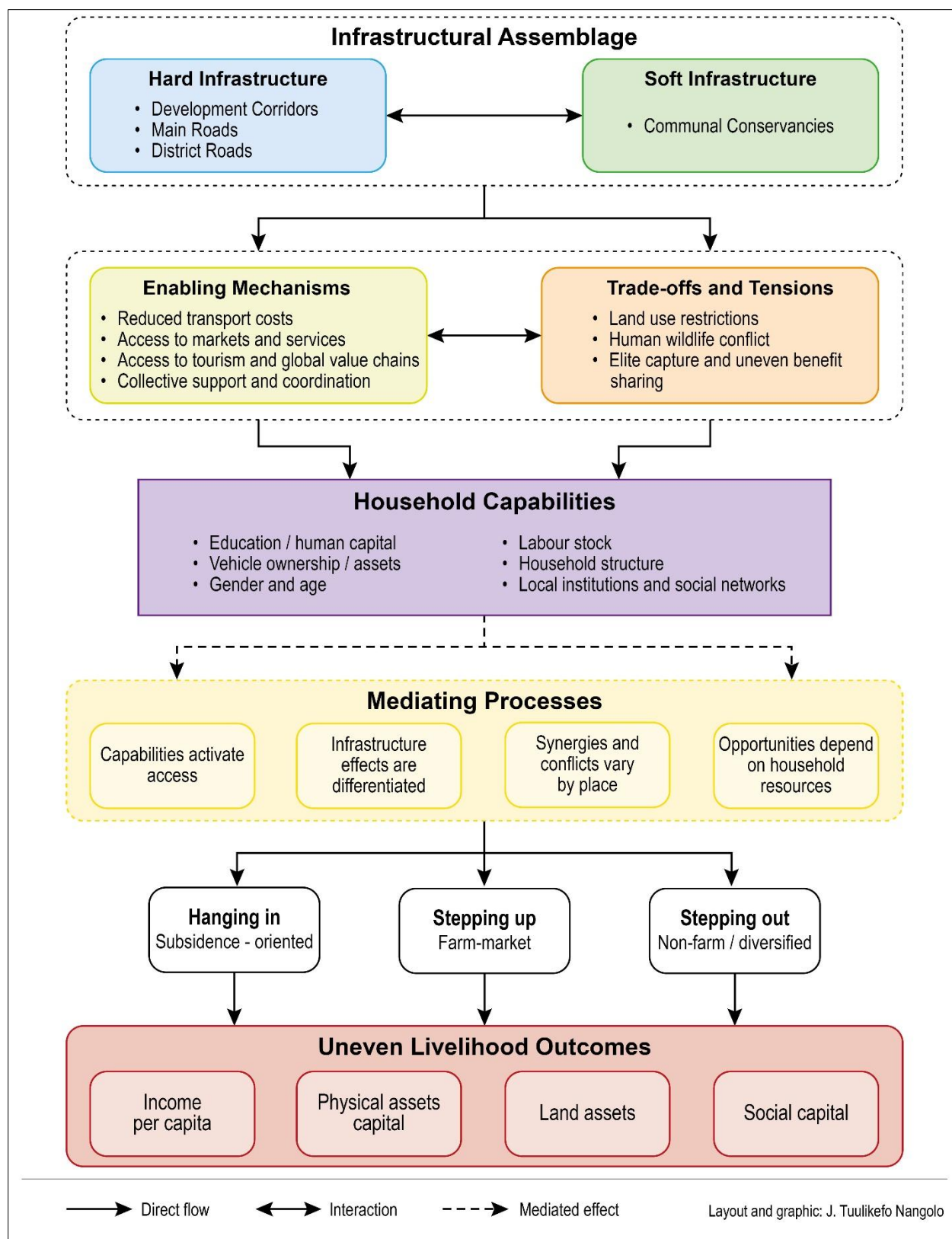


Figure 18: Conceptual Framework

6.3 Methods and Materials

6.3.1 Data and Study Variables

Our analysis focuses on Zambezi Region (Figure 19) and uses two waves of household survey data collected in 2019 and 2023 (Gebrekidan et al., 2021, 2024). Of the 652 households initially surveyed, 548 households were observed with complete information in both waves, yielding a balanced panel of 1,096 household-year observations. Households were categorised into three categories based on their livelihood activities and their observed changes in livelihood strategies between the two years of observation: Subsistence -oriented, farm-market and non-farm / diversified households. Subsistence-oriented households depends on their farming activities (livestock and crop) for own consumption and partake in no sort of selling their produce. These households have no additional source of income such as employment however they often rely on remittances and pension when possible. Farm-market households sell part of their agricultural produce for income generation. Similar to subsistence these household have no formal, informal employments as well as other business activities outside of their engaged farming activities. They may also have remittances or pensions as supplement. Non-farm / diversified households have an additional source of income from employment or business activities beyond agricultural farming. To understand how households interact with infrastructure, we map out their dynamic pathways between livelihood typologies from 2019 and 2023 using 2019 as the baseline (Table 8). Households classified as subsistence-oriented in 2019 and remains in the same state in 2023 are classified as hanging in. Meanwhile households that transitioned from subsistence-oriented in 2019 to farm-market in 2023 are classified as stepping up. Household that uses their skills or assets to move either from subsistence or farm-market into non-farm / diversified by 2023 are classified as stepping out.

Table 8: Livelihood transition matrix between 2019 and 2023

2019 baseline	2023 Outcome	Transition
Subsistence-oriented	Subsistence-oriented	Hanging in

Subsistence-oriented	Farm- Market	Stepping up
Subsistence-oriented	Non-farm / diversified	Stepping out
Farm- Market	Non-farm / diversified	Stepping out
Farm-market	Subsistence-oriented	Stepping out
Non-farm/diversified	Subsistence-oriented	Stepping out

These typologies are then used to examine how accessibility to infrastructure is associated with livelihood outcomes. Livelihood outcomes are represented by four household level indicators: log net income per capita, asset index, land index and social capital (Appendix A.6). Income per capita is defined as annualised household income from various sources including crops, livestock, business, employment and other sources such as remittance, pensions and transfer divided by the household size. Asset index is created from a principal component analysis of household asset, housing conditions and durable goods. To reduce noise and improve robustness variables with low variations were removed using a sparsity filter. The asset index is derived from the PCA as the first PCA that represent the standardised variables that represents the largest variability within the households. The same PCA approach is applied to construct the land index, social capital index, and Human Capability Index. Land index summarises land use and ownership information for individual households. Meanwhile, social capital represents the households' embeddedness into social networks by creating an index based on how many organisations each household are embedded in, ranging from, religious, financial and conservancies as well. The Human Capability Index is created to capture human capabilities at household levels, combining information on education, demographic and labour engagements using individual-level data from household members.

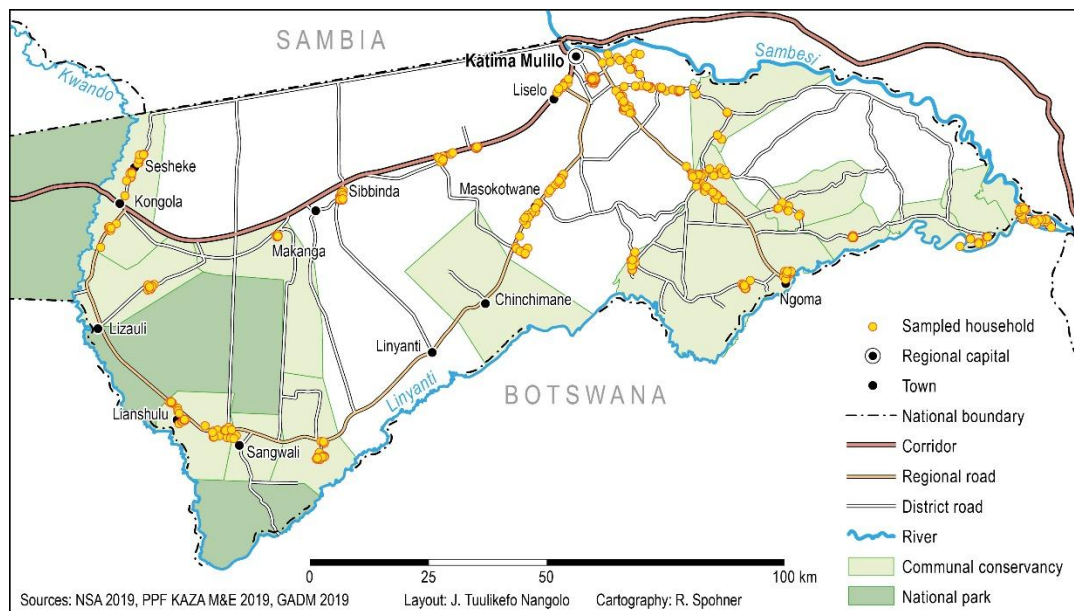


Figure 19: Map of the study area and sampled household

Proximity to Infrastructure

Proximity to infrastructure is calculated using a network analysis that reflects the travel time from individual households to the nearest infrastructure along the road network. The road network dataset for the Zambezi Region was sourced from the Namibian Roads Authority via the Namibia Statistics Agency's Digital Namibia platform for data sharing. Official information on Namibian road rules and speed regulations was used to inform the travel time based on distance and road type to measure accessibility. Three road types were used in creation of the road network including: trunk roads (tarred national roads connecting to neighbouring countries including development corridor), main roads (paved roads linking key centres and towns), and district roads (mostly bitumen or earth roads connecting villages). Speed limit of 120km/h was used for both trunk and main roads, while 80km/h and 3.8km/h is used for district roads and straight-line walking distance respectively. These speed limits were used to reflect the average travel on flat surfaces like the Zambezi Region. Household proximity to infrastructure is calculated based on distance to specific infrastructure (development corridors, main road, and district road) and by indication whether they are located within communal conservancies. Initial distance to the nearest road was calculated using straight-line walking time and distance.

Subsequent travel followed the road network, adjusting speeds by road type (district, main, or trunk). This yielded metrics for distance to market, nearest district road, nearest main road and development corridor for individual households. Because the infrastructure variables are measured as travel time, they must be interpreted carefully. Larger values indicate longer travel times and poor accessibility/proximity. In this study, a negative coefficient means that shorter travel time is associated with higher values of the outcome, while a positive coefficient indicates lower outcome values. The analysis for access to infrastructure were carried out in Google Collab and R studio.

6.3.2 Econometric Framework

To establish baseline differences between livelihood groups, we applied Welch's analysis of variance due to unequal variances and sample sizes in groups' data to fully understand whether the mean differs significantly between various groups.

Baseline Livelihood Typologies

To analyse the association of infrastructure and livelihoods, we employ a Mundlak hybrid Random Effects approach on the balanced panel dataset from two waves of analysis (2019 and 2023) to account for time-invariant variable while controlling for unobserved heterogeneity (Mundlak, 1978; Schunck, 2013; Wooldridge, 2025). We divide our balance panel into three livelihood typologies groups based on their livelihood: G1 (Subsistence-Oriented), G2 (farm-market), and G3 (Non-farm/Diversified). We use Mundlak Hybrid model because it allows for the inclusion of time-invariant infrastructure variables while controlling for correlated unobserved heterogeneity through household level means. Let Y_{it}^G denote the livelihood outcomes for household i in year t such as log income per capita, asset index, land index or social capital for the household in group G where G is 1 if subsistence oriented, 2 if farm market and 3 if non-farm /diversified. We estimate:

Equation A.1

$$Y_{it}^G = \beta_0^G + \beta_1^G X_{it} + \beta_2^G Z_i + \beta_3^G \bar{X}_i + \beta_4^G T_t + \varepsilon_{it}^G$$

Where X_{it} represents different combination of the time varying household characteristics. Z_i is the vector of time-invariant characteristic such as travel time and whether household is inside or outside a communal conservancy. $\bar{X}_i$ represents Mundlak means for the household level averages of the time varying covariate serving as controls for unobserved heterogeneity and T_t represents the year dummy variable, which equals 1 for 2023 with 2019 as the reference year to capture aggregate shocks and ε_{it}^G is the error term.

Infrastructure Interactions

We estimate interaction models to test whether the effect of infrastructure depends on household capabilities such as education, labour stock, vehicle ownership or other different components of infrastructural assemblage such as hard vs soft infrastructure. In this way, we test how different components of the infrastructural assemblage work together to shape livelihood outcomes. In this specification, we are interested in understanding which elements of infrastructural assemblages reinforce one another or generate trade off. The following specification issued in this model:

Equation A.2

$$Y_{it}^G = \beta_0^G + \beta_1^G X_{it} + \beta_2^G Z_i + \beta_3^G \bar{X}_i + \beta_4^G (Z_i \times C_i) + \beta_5^G (Z_i \times S_i) + \beta_6^G T_t + \varepsilon_{it}^G$$

Where C_i represents the capability variables such as education, labour stock and vehicle ownership, S_i represents soft infrastructure variable of communal conservancies and Z_i represents the hard infrastructure element such as development corridor, main road or district roads.

Livelihood market entrance and transitions

Next, we employ a multinomial probit (Roodman, 2011) to examine the transitions across three livelihood groups explain and to explain which household characteristics are associated with movement from subsistence to farm-market and non-farm/ diversified livelihoods. The multinomial probit allows us to estimate the probability of alternative discrete livelihood outcomes overtime which specific variables are important for market entrance. The following specification is used:

Equation A.3

$$P(\text{Market}_{it}^G = 1 | V_{it}) = \Phi(\delta_0 + \delta_1 X_i + \delta_2 Z_i + \delta_3 \bar{C}_i + \delta_4 \bar{x}_i)$$

Let $P(\text{Market}_{it}^G = 1 | V_{it})$ denote the probability of a household to engage in farm market or non-farm diversified livelihood from subsistence farming. This model evaluates the two possible movement out of subsistence into the two possible groups: Market G is equals 1 if the household has entered the farm-market group (G=2) and remains G=0 if they remain in subsistence livelihood. The market is equals 1 if the household has moved into non -farm diversified livelihood (G=3) and remains 0 if the stay in subsistence. Significant coefficients reflect which variables are necessary conditions for market entry.

Lastly, we estimate a multinomial probit model to analyse dynamic livelihood transitions (Table A.1) across livelihoods groups using 2019 baseline livelihoods. This is helpful to understand the mechanisms driving upward or downward movement over time. The model is specified using the following equation

Equation A.4

$$P(\text{Transition}_{i,2023}^G = 1 | \text{Sub}_{i,2019} = k) = \Phi(\lambda_0 + \Gamma_1 X_{i,2019} + \Gamma_2 Z_{i,2019} + \Gamma_2 \bar{C}_{i,2019} + v_i)$$

Let $(\text{Transition}_{i,2023}^G = 1 | \text{Sub}_{i,2019} = k)$ denote the change in welfare outcomes between 2019 and 2023. The framework maps these movements into five distinct trajectory pathways across three baseline origins. For households originating from the Subsistence baseline (k=1), the model tracks pathways which represent movement stepping up (farm-market 0 or stepping out (non-farm diversified). Households with a baseline of farm-market in 2019 (k=2), the model captures pathways of stepping out (non-farm-market) as well as movement into subsistence. Lastly, for households originating in the non-farm diversified baseline (k=3), the model traces pathways moving into subsistence.

6.3.3 Robustness Checks

We perform several robustness checks to validate our main findings in Appendix A.7. First, we estimate standard fixed effects models to ensure that the coefficients on time

varying variables (e.g. diversification) remain consistent with the Mundlak estimates. Second, we drop the richest 5% to assess that our findings are not just a result of the outliers driven by the few wealthy elites. Next, we drop the 10% households living closest to the development corridor to prove that infrastructure results are not just a result of those inside the towns but reflects the connectivity along the region and various routes. Finally, we estimate models excluding the diversification count to verify the direct impact of specific income sources

6.4 Results

6.4.1 Descriptive Information

Table 9 summarises the characteristics of the sampled 1096 observations. All values are reported as means, with standard deviations in parentheses.

In terms of livelihood outcomes, the non-farm / diversified households exhibit the highest asset wealth and income per capita across all years compared to the other two groups. These two outcomes are statistically significant at the 1% level (***) between the three groups. Meanwhile, the Land Index and social capital Index are not statistically significant (ns), showing mixed outcomes across all groups and implying minimal differences in these variables based on household typology. Regarding infrastructure, there are almost no statistical differences between the livelihood typologies. Travel times to development corridors, district roads, and the nearest markets are similar across all groups, with no statistical significance. A marginal significance (*) is observed only in the time to main roads. Similarly, conservancy status is non-significant; living inside a conservancy does not determine the type of livelihood a household engages in.

Table B.1 indicates that the variables significantly differentiating the livelihood groups are the education of the household head (HCI Leadership), the dependency ratio, the age of the household head, and Livelihood Diversification, all of which are significant at the 1% level (***). Subsistence and farm-market households are headed by significantly older individuals compared to non-farm / diversified households. For example, in 2023, the mean age for farm-market heads was 59.32 years, whereas it was 48.71 years for non-farm heads. Additionally, the dependency ratio in the non-farm / diversified group is lower compared to the other two groups.

Table 9: Household description by source of income. Mean (standard deviation) in each cell. Market = Off-Farm employment

Variable	2019 Wave			2023 Wave			Group Diff
Variable	Subsistence	Farm-market	Non-Farm	Subsistence	Farm-market	Non-Farm	Sig
Income per Capita (log)	5.49 (3.58)	6.46 (3.46)	7.44 (2.61)	5.07 (3.71)	5.84 (3.72)	7.72 (3.12)	***
Asset Accumulation Index	-0.16 (1.65)	-0.19 (1.44)	0.2 (1.64)	-0.33 (2)	0.1 (2.28)	0.45 (2.36)	***
Land Index	-0.03 (1.46)	0.67 (1.7)	-0.15 (1.37)	0.11 (1.25)	-0.33 (1.8)	-0.05 (1.5)	ns
Social Capital Index	-0.09 (1.07)	-0.01 (1.13)	0.04 (1.14)	-0.02 (1.17)	-0.04 (1.01)	0.11 (0.84)	ns
HCI: Leadership Pillar	-0.22 (1.02)	0.08 (1)	0.12 (0.95)	-0.18 (1)	-0.09 (1.05)	0.25 (0.9)	***
HCI: labour stock	0.11 (1.02)	0.12 (1.15)	0.12 (1.03)	-0.24 (0.94)	-0.07 (0.92)	0.09 (0.92)	**
Educated Adults (Stock)	2.04 (1.33)	2.05 (1.5)	2.06 (1.35)	1.58 (1.23)	1.81 (1.21)	2.01 (1.21)	**
Household Size	5.23 (2.6)	5.16 (2.58)	5.11 (2.32)	5.02 (2.5)	5.23 (2.29)	5.25 (2.33)	ns
dependency ratio	0.5 (0.25)	0.5 (0.27)	0.45 (0.24)	0.5 (0.25)	0.51 (0.26)	0.42 (0.22)	***

Variable	2019 Wave			2023 Wave			Group Diff
Variable	Subsistence	Farm-market	Non-Farm	Subsistence	Farm-market	Non-Farm	Sig
Age of Household Head	55.62 (17.53)	54.19 (17.6)	47.94 (16.52)	55.46 (17.14)	59.32 (14.56)	48.71 (13.34)	***
Time to Corridor (log min)	3.4 (0.96)	3.57 (1.19)	3.4 (1.26)	3.36 (0.97)	3.47 (1.23)	3.51 (1.4)	ns
Time to main road (log min)	2.38 (1.18)	2.63 (1.47)	2.58 (1.39)	2.43 (1.14)	2.66 (1.34)	2.6 (1.57)	*
Time to District Road (log min)	1.82 (0.87)	1.95 (0.87)	1.75 (0.87)	1.82 (0.85)	1.82 (0.86)	1.67 (0.84)	ns
Time to Market (log min)	3.7 (0.86)	3.96 (1.04)	3.67 (1.13)	3.64 (0.91)	3.76 (1.06)	3.84 (1.27)	ns
Inside Conservancy (Dummy)	0.59 (0.49)	0.68 (0.47)	0.51 (0.5)	0.57 (0.5)	0.54 (0.5)	0.56 (0.5)	ns
Livelihood Diversification	0.78 (0.42)	1.75 (0.43)	2.27 (0.75)	0.72 (0.45)	1.73 (0.45)	2.03 (0.74)	***
N	185	73	290	288	115	145	

Note: Infrastructure variables are measured as spatial time, thus lower value indicates shorter travel times and better access. Negative coefficients should therefore be interpreted as the better accessibility the higher the outcomes as vice versa. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively

6.4.2 Livelihood Strategy

To fully understand the drivers of participation in various livelihood groups, we compared households engaged in farm-market and non-farm (diversified) activities to those still dependent on a traditional subsistence way of life. Table 10 reveals that infrastructure shapes livelihoods differently across the three typologies. Shorter travel time to district roads is significantly associated with asset accumulation across all typologies; however, development corridors show no significant association with either income or assets for any group. Vehicle ownership yielded some of the most compelling results; it is positively and significantly associated with income for both farm-market (2.60^{***}) and non-farm (1.04^{**}) households, but shows no significance for the subsistence group. This indicates that roads are only effectively utilised for market access or employment when households possess the necessary means of transport. Interestingly, high education levels of the household head (HCI: Leadership) are negatively associated with income in both the subsistence (-0.34^{***}) and farm-market (-0.55^{**}) groups. This suggests a mismatch in skill sets, where educated individuals remain trapped in subsistence-based typologies. Table B. 2 further indicates that household size has a negative effect on income per capita across all groups. Meanwhile, the age of the household head has a positive and significant effect on income per capita for subsistence households (1.11^{**}) and a positive effect on assets for both subsistence and market-engaged households, although at varying significance levels.

Table 10: Livelihood Divergence

	Income Per Capita			/	Asset Index			/
	Subsistence-Oriented	Farm-market	Nonfarm Diversified		Subsistence-Oriented	Farm-market	Non-farm Diversified	
Time Corridor to	0.18 (0.31)	0.20 (0.63)	-0.19 (0.38)		0.06 (0.71)	-0.31 (0.17)	0.09 (0.52)	
Time to main road	-0.11 (0.39)	0.33 (0.34)	0.33 (0.08) *		0.48 (<0.01) ***	0.44 (0.02) **	0.41 (<0.01) ***	
Time to District Road	-0.23 (0.04) **	-0.09 (0.76)	-0.04 (0.81)		-0.31 (<0.01) ***	-0.40 (0.01) **	-0.32 (<0.01) ***	
Time Market to	-0.17 (0.44)	-0.54 (0.37)	-0.17 (0.57)		-1.09 (<0.01) ***	-0.40 (0.21)	-0.58 (<0.01) ***	
HCI: Leadership	-0.34 (<0.01) ***	-0.55 (0.04) **	-0.11 (0.47)		0.09 (0.27)	0.28 (0.04) **	0.30 (<0.01) ***	
HCI: labour stock	-0.05 (0.68)	0.11 (0.71)	-0.05 (0.76)		0.28 (<0.01) ***	0.20 (0.20)	0.14 (0.17)	
Vehicle Ownership	-0.26 (0.57)	2.60 (<0.01) ***	1.04 (0.02) **		2.78 (<0.01) ***	2.02 (<0.01) ***	1.63 (<0.01) ***	
Livelihood Diversification	6.93 (<0.01) ***	2.47 (<0.01) ***	0.60 (<0.01) ***		0.29 (0.11)	0.39 (0.21)	0.04 (0.72)	
Inside Conservancy	0.17 (0.49)	0.68 (0.35)	0.56 (0.14)		0.74 (<0.01) ***	-0.25 (0.52)	-0.20 (0.40)	
Household Size	-0.08 (0.06) *	-0.25 (0.04) **	-0.20 (<0.01) ***		0.02 (0.54)	-0.06 (0.35)	0.03 (0.49)	
Female Head	-0.10 (0.57)	-0.58 (0.26)	0.28 (0.29)		-0.08 (0.62)	0.08 (0.78)	-0.15 (0.39)	
Year: 2023	-0.01 (0.97)	-0.77 (0.15)	0.55 (0.06) *		-0.05 (0.75)	0.06 (0.84)	0.24 (0.18)	

Income Per Capita				Asset Index				
	Subsistence- Oriented	Farm- market	Nonfarm Diversified	/	Subsistence- Oriented	Farm- market	Non-farm Diversified	/
Constant	1.11 (0.04) **	3.89 (0.02) **	7.08 (<0.01) ***		2.19 (<0.01) ***	1.74 (0.05) *	1.23 (<0.01) ***	
Num.Obs.	473	188	435		471	188	435	
R2	0.730	0.198	0.071		0.254	0.269	0.210	
Note: Infrastructure variables are measured as spatial time, thus lower value indicates shorter travel times and better access. Negative coefficients should therefore be interpreted as the better accessibility the higher the outcomes as vice versa. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively								

6.4.3 Interactions

To fully understand the assemblages of individual infrastructure as well as their combined associations, Table 11 presents the interactions among different infrastructure variables, household capabilities, and livelihood outcomes. The results suggest that infrastructure is more strongly associated with livelihood gains when combined with specific household capabilities. For instance, the interaction between vehicle ownership and distance to the development corridor yields a positive and significant effect on physical assets (0.32**). Because the baseline effect of distance is typically a penalty, this positive interaction may suggest that for households owning vehicles, the cost of spatial friction is neutralised. Private mobility allows these households to overcome their remote locations and successfully accumulate higher assets. Similarly, human capital, especially the average education level of the household (labour stock) may act as institutional shield. The interaction between household labour stock and distance to both the corridor and district roads has a highly significant, positive effect on asset accumulation (0.26*** and 0.20***, respectively). This suggests that physical roads do not automatically deliver wealth; rather, roads only generate material benefits for households equipped with the educational capacity to exploit new economic flows and market information.

Furthermore, we observe a spatial divergence in the role of communal conservancies, which appears to interact differently with accessibility to infrastructure and livelihoods outcomes. The interaction between conservancy and distance to the main corridor is positive and highly significant across all livelihood capitals (Income, Assets, Land, and social capital). This suggests that the financial and social benefits of conservancies are maximised in remote places located further away from the corridors. This may indicate that conservancies partly compensate for weaker corridor access in peripheral areas. However, the interaction between living in a conservancy and distance to local district roads is highly significant and negative for both physical assets (-0.21**) and land assets (-0.15**). This suggests that households located inside conservancies and far from local district feeder roads face severe limits on asset accumulation and land holdings. This means that while conservancies provide income in remote areas, their strict conservation

zoning rules and the resulting human-wildlife conflict actively suppress a household's ability to expand their agrarian footprint or build permanent physical structures.

Table 11: Interactions Between Corridor Proximity, Household Capabilities, and Conservancy Status

	Income	Assets	Land	Social Capital
Vehicle × Development Corridor	-0.01 (0.96)	0.32 (0.02) **	-0.01 (0.93)	0.09 (0.26)
Labour Stock × Development Corridor	0.06 (0.54)	0.26 (<0.01) ***	0.01 (0.86)	0.09 (<0.01) ***
Labour Stock × District Road	-0.03 (0.79)	0.20 (<0.01) ***	-0.08 (0.09) *	0.03 (0.40)
Vehicle × District Road	0.30 (0.50)	0.44 (0.06) *	0.11 (0.59)	0.10 (0.51)
Conservancy × Development Corridor	0.22 (0.02) **	0.11 (0.05) *	0.07 (0.08) *	0.07 (0.02) **
Conservancy × District Road	-0.11 (0.43)	-0.21 (0.01) **	-0.15 (0.01) **	-0.03 (0.46)
Labour stock × Market Access	-0.08 (0.25)	-0.21 (<0.01) ***	0.03 (0.39)	-0.06 (0.01) **
Year: 2023	-0.77 (<0.01) ***	0.03 (0.70)	-0.02 (0.86)	0.05 (0.44)
Constant	4.21 (<0.01) ***	0.78 (<0.01) ***	-0.13 (0.52)	0.18 (0.21)
Num.Obs.	1096	1094	1096	1088
R2	0.127	0.151	0.011	0.029
Note: *, **, and *** indicate significance at 10%, 5%, and 1%, respectively				

6.4.4 Market Entrance and Transitions

To identify the variables that predict the transition from subsistence farming to market engagement and non-farm livelihoods, Table 12 presents estimates for market participation. The results indicate that shorter travel time to district roads are significantly associated with higher likelihood of entering both farm-market (-0.09*) and non-farm / diversified livelihoods (-0.14***). However, interestingly, longer travel time to main roads is also surprisingly associated with higher probability of entering a farm-market livelihood (0.10*). Education of the household head (HCI: Leadership) is the most significant

positive predictor for both farm-market (0.15^{***}) and non-farm (0.09^{*}) entry. Vehicle ownership also plays a critical role, showing strong positive significance for both farm-market (0.39^{**}) and non-farm (0.36^{**}) participation. Conversely, results show that older heads of households are less likely to transition into these market-engaged groups. Additionally, the year dummy for 2023 shows large, negative, and significant coefficients (-0.49^{***} and -0.74^{***}), suggesting that maintaining active market participation was considerably more difficult in 2023 compared to the 2019 baselin

Table 12: Probability of Market Participation

	Entry: market	farm- Entry: non-farm / diversified
Dist. Corridor (log min)	-0.09 (0.21)	-0.03 (0.72)
Dist. main road (log min)	0.10 (0.06) *	0.09 (0.11)
Dist. District Road (log min)	-0.09 (0.08) *	-0.14 (<0.01) ***
Dist. Market (log min)	0.12 (0.20)	0.02 (0.81)
HCI: Leadership	0.15 (<0.01) ***	0.09 (0.08) *
HCI: labour stock	0.03 (0.43)	0.04 (0.33)
Vehicle Ownership	0.39 (0.02) **	0.36 (0.02) **
Inside Conservancy	-0.12 (0.26)	-0.11 (0.32)
dependency ratio	-0.02 (0.46)	-0.03 (0.29)
Head Age	-0.00 (0.07) *	-0.01 (<0.01) ***
Year: 2023	-0.49 (<0.01) ***	-0.74 (<0.01) ***
Constant	0.55 (0.03) **	1.03 (<0.01) ***
Num.Obs.	1096	1096
Note: Infrastructure variables are measured as spatial time, thus lower value indicates shorter travel times and better access. Negative coefficients should therefore be interpreted as the better accessibility the higher the outcomes as vice versa. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively		

Table 13 models the dynamic transitions of households in 2019 to determine their status by 2023. We examine the probability household movement between different livelihood typologies. Notably, proximity to infrastructure at the 2019 baseline had no statistically significant association with transitioning from subsistence households. However, we find a negative association with households transitioning from farm-market to non-farm diversified and development corridor. Instead, we find that transitioning pathways are based on household-specific assets and demographics. The probability of transitioning into non-farm livelihoods is primarily driven by whether households had a vehicle in 2019 (0.73*). Demographic factors are also critical; households with younger heads (-0.01*) and a lower dependency ratio (-0.16**) are significantly more likely to transition. Transitioning into farm-market livelihoods is positively driven by the initial land index (0.12*). Conversely, a higher baseline labour stock significantly reduces the probability of stepping up into these specific commercial activities (-0.22*)

Table 13: Transition probability to various livelihood pathways 2019-2023

Variable	Subsistence to farm-market (Step Up)	Subsistence to non-farm (step out)	Farm-Market to non-Farm	Farm-market to subsistence	Non-farm to subsistence
Time to development Corridor	0.16 (0.18)	-0.18 (0.23)	0.49 (0.02)**	-0.15 (0.35)	-0.11 (0.11)
Time to District Road	-0.10 (0.44)	0.07 (0.66)	-0.27 (0.29)	0.04 (0.85)	0.02 (0.83)
HCI: Leadership	0.01 (0.91)	0.15 (0.28)	0.21 (0.38)	-0.37 (0.04)**	-0.18 (0.05)*
Vehicle ownership	0.42 (0.31)	0.73 (0.09)*	0.74 (0.40)	0.15 (0.83)	-0.38 (0.16)
Head Age	0.00 (0.72)	-0.01 (0.36)	-0.02 (0.15)	-0.00 (0.71)	0.00 (0.72)
Land Index	0.12 (0.10)*	0.01 (0.86)	-0.08 (0.52)	-0.08 (0.40)	-0.11 (0.06)*
Conservancy	-0.05 (0.84)	-0.19 (0.47)	1.57 (0.01)**	-0.30 (0.39)	0.04 (0.79)
dependency ratio	-0.01 (0.83)	-0.14 (0.06)*	-0.38 (0.06)*	0.05 (0.65)	0.07 (0.15)
Constant	-1.31 (0.03)**	0.29 (0.65)	-1.44 (0.23)	0.82 (0.32)	0.00 (1.00)
Num.Obs.	185	185	73	73	290

Note: Infrastructure variables are measured as spatial time, thus lower value indicates shorter travel times and better access. Negative coefficients should therefore be interpreted as the better accessibility the higher the outcomes as vice versa. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

6.4.5 Robustness Checks

Robustness checks in Appendix A.7 confirm the stability of key results. Livelihood diversification remains the most robust predictor of income across specifications, with the coefficient remaining virtually unchanged between the Baseline Mundlak RE (2.043^{***}) and the Within-Household Fixed Effects (2.037^{***}) models. The significance of Vehicle Ownership (0.801^{**}) disappears when the wealthiest 5% of households are excluded, suggesting that the vehicle ownership is concentrated among wealthier households. Infrastructure coefficients (corridors, main roads, district roads, conservancies) remain stable across specifications, suggesting that household composition and diversification although their significance varies across specification suggesting careful interpretation.

6.5 Discussion

Our study aimed to move beyond looking at infrastructure independently by conceptualising development corridor, main roads, district roads, and communal conservancies as an infrastructural assemblage. The findings show that infrastructural assemblages do not produce uniform livelihood benefits; rather, their effects depend on spatial logics, institutional overlaps and household capabilities. This paper offers a contribution to current debates in economic geography through its discussion on how infrastructural assemblage leads to uneven development, spatial selectivity and territorial governance.

6.5.1 Heterogeneous Association of Infrastructural Assemblage

Our results show that infrastructure has differential associations to rural livelihoods. District roads support locally embedded asset accumulation, corridors are more selective, and conservancies strengthen social capital but do not automatically improve income or assets.

District roads are associated with better livelihood outcomes across most dimensions but most important, better access to district roads is significant for income and assets for subsistence households as well as for transitioning out of subsistence into farm market and no farm livelihoods. Our findings are consistent with finding from other studies that shows that rural residents with lower income benefit more from improved infrastructure (Lu et al., 2023; Mulongo et al., 2020; H. Zhang et al., 2023; Y. Zhang et al., 2023). In overall the results suggest that district road facilitate place specific livelihood improvement by reducing transport costs and connecting households to nearby markets. Development corridors are less significant and not consistent with any livelihood outcomes. However, they become significant only once combined with other variables which indicates that they are selective to household with high education or vehicles. Our results are in agreement with findings from elsewhere that found large-scale infrastructure such as development corridors may lead to uneven outcomes and produce winners and losers (Bignoli et al., 2024; Enns et al., 2022; Scholvin, 2021; Sengupta et al., 2016; Zheng, 2025). These findings suggests that development corridors might benefit already better off households

and thus deepen spatial inequalities and lead to uneven livelihood outcome. Communal conservancies are associated with higher social capital but not high income or assets. Our findings are in contradiction with the expectation of communal conservancies when it comes to income generation. Instead, our findings suggest that communal conservancies are selective in their benefits. This is shown in the transition results whereby conservancy status is significantly associated with the transition from farm-market to non-farm/ diversified livelihood indicating their role in diversification rather than broader income benefits. The results align with the Meyer & Börner (2022) results who found that communal conservancies can increase income and livelihood diversity. Our results indicate that infrastructural assemblages are spatial selective in their outcomes where by some infrastructures are strategically beneficial to some livelihoods (Jones et al., 2015).

6.5.2 Infrastructural assemblage and spatial conflict

Our results reveal that when soft infrastructure interacts with hard transport infrastructure the infrastructural assemblage produces differential outcomes. Our results demonstrate that the interactions within this assemblage do not always reinforce each other but they may generate trade-offs when their logics are misaligned.

First, a complementary logic is found between communal conservancies and development corridor. Although conservancies and development corridors showed no significant positive association with income or assets when analysed individually, their interaction is positively associated with income and assets. This could suggest that development corridors may benefit communal conservancies in connecting them to wider global markets and tourism. Secondary, a trade off is found between communal conservancies and district roads. The interaction of district roads with communal conservancies is significantly associated with negative outcomes across all livelihood indicators. This is despite the fact that district roads have a significant association with income and assets before interactions. District roads are meant to facilitate local connectivity and agricultural intensification, while communal conservancies enforce strict land use zoning and prioritise conservation that might restrict agricultural intensification. Our results demonstrate how the outcomes of infrastructure is depended on the

assemblage components in space The assemblage theory is made up of interacting socio-material and institutions that can either complement each other or produce tensions and shape the outcomes of the assemblage (Deleuze & Guattari, 1987; Müller, 2015). In our case, the results show how the infrastructural assemblage components produce different livelihood outcomes when interacted depending on their logics. This understanding of how infrastructure assemblages interact in different ways at different times is necessary to understand livelihoods (Battersby et al., 2024).

6.5.3 Mediating Role for Household Capabilities

Finally, our findings demonstrate that physical proximity to infrastructure does not automatically generate benefits; household capabilities such as education, labour stock, vehicle ownership and household structure, determines whether access can be converted into livelihood gains. These results are consistent with the conceptual framework and support the debate that infrastructure needs to be complemented by capabilities. Without the necessary skills and capabilities, it yields weak returns. The conceptual framework developed in this study identify household capabilities such as education, vehicle ownership, labour stock and household structure as mediating process that activate access, generate differentiate effects, create synergies and conflicts that may vary by place and also depends on household resources. These capabilities then determine how households are moving between livelihood typologies. District roads provide access to markets; however, our results suggest that when combined with households with higher labour stock and vehicle ownership the access is turned into productive gain. Similarly, development corridors are weak and inconsistent when looked at separately, however when combined with vehicle ownership and labour stock they are positively associated with asset and social capital. These results show how households may have access to infrastructure but may not benefit due to lack of necessary capabilities to unlock them and thus create winners and deepen existing spatial inequalities. These results are consistent with result from Papua New Guinea, where upgrading roads supported household structural transformation from subsistence farming to market-oriented activities (Wiegand et al., 2023). Similarly (Mutsami et al., 2025) and (Gertler et al., 2022) show that roads only raise welfare when they facilitate a shift from farm to non-farm labour. Our results

show that stepping up and out of the subsistence livelihood requires passing through these capabilities. Without human capital and skills, roads simply reshape where assets are located without improving livelihoods. The results contribute to the discussion on roads are not enough (Dawson & Barwell, 1993), there is a need to bundle them up with other skills (Athukorala & Narayanan, 2018; Sieber & Allen, 2016) such as education or employment as found in this study. This means that access to infrastructure is highly effective when households have the skills and assets needed to use improved access. This proves that a highly educated household head is only associated with significantly higher income when they have the infrastructure to reach the market, and conversely, a development corridor only generates local wealth when the population has the education and leadership capabilities to navigate it.

Taken together, our results contribute to economic geography by showing that infrastructural assemblages generate uneven rural transformation through spatial selectivity, institutional trade-offs and capability-mediated access. Firstly, the results reinforce uneven development whereby infrastructural assemblages' components generate differentiated effects across livelihood typologies. Secondly, they also show infrastructure benefits are spatially selective, certain groups benefit more depending on their location and capabilities. Thirdly, this paper demonstrated that rural development and livelihoods are dependent on interacting and relational system of hard infrastructure and soft infrastructure that may complement or create tensions and cause differentiated outcomes. For instance, developing development corridors without integrating local district roads may disproportionately concentrates wealth among elites, driving what Athukorala & Narayanan (2018) refer to as spatial sorting and unequal agglomeration, whereby only a certain group benefits from the improved access. Similarly, creating communal conservancies without considering employment opportunities may only create institutional networks that regulate access and highlight territorial governance without generating benefits. Our results reinforce debates on infrastructure-led development in general by proving that access to infrastructure alone without simultaneous investments in employment and human capabilities leaves households hanging in subsistence activities, fully reliant on remittances for survival. Therefore, creating strategies that allows

for coordinated choices across these infrastructures and capabilities rather than isolated investments in single infrastructure is recommended.

6.6 Conclusion

This study contributes to the literature on the heterogeneous outcomes of infrastructure by conceptualising the overlapping realities of hard and soft infrastructure in Namibia's Zambezi Region as an infrastructural assemblage. Using a two-wave panel dataset from 2019 and 2023, the study assessed how proximity to development corridors, district roads, main roads, and communal conservancies are associated with livelihood outcomes. Our findings demonstrate that infrastructural assemblages produce uneven and differentiated outcomes that are selective and dependent on household capabilities. District roads are associated with asset accumulation across various livelihood typologies. Development corridors are selective in their outcomes and benefit better off households more. Communal conservancies are associated with higher social capital, but they do not automatically improve income or assets. The interaction results further show that infrastructural components have different spatial logics that do not always reinforce one another revealing both complementarities and trade-offs. Our results show that the infrastructural assemblage is highly mediated by the role of household capabilities and that this interaction shapes livelihood pathways. For instance, households with better capabilities, such as an educated household head, higher household education stock, and vehicle ownership, are more likely to step up into farm-market livelihoods or step out into non-farm / diversified livelihoods. By contrast, households with weaker capabilities are more likely to remain hanging in subsistence farming. These findings challenge the narrative that infrastructure is a standalone driver for economic and rural development. Instead, it suggests that infrastructure should be understood as an assemblage of interacting components. This study therefore makes three contributions to the literature: (1) it conceptualises infrastructural assemblage as made out of hard and soft infrastructure including regional roads, development corridors and communal conservancies; (2) it uses panel data to show that this infrastructural assemblage can lead to differentiated livelihood pathways; (3) it also demonstrates that household capabilities mediate whether infrastructure access can be converted into livelihood outcomes.

Disclosure Statement

No potential conflict of interest was reported by the authors.

Data Availability

The datasets used in this study are openly available at <https://www.trr228db.uni-koeln.de/search/view.php?doiID=25> and <https://www.trr228db.uni-koeln.de/search/view.php?doiID=9>.

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7 Synthesis

The aim of this dissertation was to examine how infrastructure-led development produces uneven development using the Walvis Bay Ndola Lubumbashi Development Corridor (WBNLDC) as its empirical setting. To achieve this, it (i) documented landscape transformation along the corridor and regional roads, using land use change as a proxy for economic change; (ii) analysed NTL as a proxy for economic activity and spatial economic patterns; and (iii) examined how different forms of infrastructure jointly shape livelihood outcomes in the Zambezi Region. Based on these empirical analyses, the dissertation identifies three dimensions through which the outcomes of development corridors are produced: spatial selectivity and uneven development, infrastructural assemblages, and differentiated capabilities. The following chapter summarises the findings of this dissertation in regard to how uneven development is produced along the WBNLDC. The subsequent sections discuss conceptual contributions, policy implications, and possible future research directions in the next sections.

7.1 Summary of Key Finding

7.1.1 Spatial Selectivity and Uneven Development

Infrastructure-led development is promoted on the expectation that improved connectivity will attract investments, promote agglomerations and generate spill overs which will produce corridor-wide integration (Dannenbergh et al., 2018; World Bank, 2009). The first set of findings shows that the completion of the development corridor has been accompanied by an expansion of land use activities in the region. The results showed that while both cropland and built-up areas expanded between 2000 and 2023, this expansion was not evenly distributed along the roads. Instead, it was much more concentrated along the regional roads and became most visible after the regional roads were tarred. Expansion is also mostly visible at certain nodes such as Kongola and Katima Mulilo which are intersections of development corridors and regional roads indicating synergies. The patterns observed here are consistent with the selective and uneven development often found within development corridors (Lesutis, 2019). These patterns also suggest that the "food hub" expectations and regional development promises associated with Zambezi Region and WBNLDC have not been realised yet.

Instead, these results reflect the spatial selectivity, whereby expansion is only seen among certain points as seen at Kongola or Katima Mulilo but there is less evidence supporting the corridor-wide growth. The outcomes however are of interest because it speak to the literature that describe corridor as “dreamscapes of modernity” that may promote vision of corridor-wide growth while prioritising global needs that do not match the local realities (Dannenberg et al., 2018; Müller-Mahn, 2020).

The NTL analysis similarly found that economic activity along the corridor has increased since its completion, but it remained concentrated in logistic hubs and tourism zones such as mining, border, and port towns that are linked to the global commodity chains. The results show limited evidence of corridor-wide integration and agglomeration instead the patterns reflected the patterns of selective integration and enclave economies with areas in between left behind. The results are reflect what political economy describes as selective integration whereby development corridors are highly embedded within the existing politically and economy space that they selectively connect places that are useful for extraction, logistics and circulation while intermediate areas are left behind, often leading to uneven development instead of the promised equitable regional development (Dannenberg et al., 2018; Schindler & Kanai, 2021; Scholvin, 2021).

Development corridors outcomes are shaped by investments they attract, institutions and land use context in which they run through. However, FDI in the region is highly concentrated in the extractive industries and much less in other sectors where spillovers are expected to create generate broader spill overs. The corridor also runs through a landscape characterised by competing land uses such as communal conservancies, community forests, and national parks which have opposing spatial logic to that of development corridor which prioritises high-speed movement of commodities and promises agricultural transformation. This reality makes it hard to attract other investments in sectors that could lead to creation of spill overs. Previous diversification attempts have been constrained by poor management, limited skills and poor markets. These conditions help explain why the corridor follows this spatial selectivity patterns.

In overall, the results shows that the development corridor selectively connects resource rich regions as well as regions that are necessary for its logistics to the global economy which leaving the area in between with less economic activity and creating extractive enclaves thereby reinforcing uneven development. The findings thus indicates that spatial selectivity is a central feature along the WBNDLDC.

7.1.2 Infrastructural Assemblages

Infrastructure-led development is often analysed in isolation, yet development corridors enter spaces where existing infrastructure systems and spatial planning regimes are already in place, and their logics may align or conflict. Infrastructure is therefore not only material but both political and socially as its outcomes are bey by who and how they are used, regulated or governed (Kanoi et al., 2022; Larkin, 2013). An assemblage perspective is useful here because it focuses on the relational configuration of socio-material components rather than single infrastructure (Hansen & Schulze, 2021; Hudalah, 2026). This dissertation follows an assemblage perspective and conceptualises the overlap of development corridors, regional roads and communal conservancies as an infrastructural assemblage of hard and soft infrastructures.

The findings reveal that different components of the infrastructural assemblage serve different purposes and lead to differentiated outcomes. Proximity to district roads is linked to asset accumulation and land use change analysis indicates that regional roads are associated stronger agricultural expansion and built-up area than the development corridor. Meanwhile, proximity to the development corridor appears to be beneficial only to better off households. This indicates that being located close to the infrastructure does not benefit everyone equally or automatically (Barry, 2020; Hine et al., 2019).

Importantly, interactions within the infrastructural assemblage may complement or undermine each other, depending on how their logics are aligned. Proximity to district roads is associated with asset accumulation; however, this becomes negative once inside the conservancies. This suggests that the spatial logics of conservation and agricultural diversification do not align. On the contrary, the development corridor shows no significant association on its own, but it becomes positively associated with all livelihood outcomes

when households are inside conservancies. This result reflects how the development corridor can amplify the effects of communal conservancies, illustrating the broader effects of the infrastructural assemblage on livelihoods. This illustrates why an assemblage perspective is useful in infrastructure-led development, showing how uneven development is produced through the interactions rather than the connectivity alone (Barry, 2020; Hudalah, 2026).

Overall, the results show both alignment and misalignment within the assemblage. Where infrastructure logics reinforces, livelihoods effects are improved, however when they are misaligned livelihood gains are constrained. These findings indicate that uneven outcome of corridor development is produced through interactions of infrastructure but not just by connectivity alone.

7.1.3 Differentiated capabilities and the livelihood outcomes

Infrastructure-led development is widely regarded as a solution to regional development challenges, based on the assumption that improved connectivity can enhance livelihoods. However, studies of rural roads and development corridors show that these benefits are not evenly distributed across households (Dannenbergh et al., 2018; Shimamura et al., 2023). The last set of empirical analysis examines how development corridors are experienced at the local level moving beyond connectivity, to explain how improved access shapes livelihoods.

The results confirm that households experience access to infrastructure differently depending on their livelihood typology. Subsistence-oriented livelihoods benefit more from proximity to district roads compared to households in non-farm / diversified livelihoods. This is consistent with the expectation that improving rural roads will benefit rural livelihoods (Asher et al., 2018). At the same time, households to move between different livelihood strategies, their differentiated capabilities are an important asset rather than connectivity on its own. Households are more likely to step up into farm market activities or step out into non-farm livelihoods when they have better education, vehicle access, stronger labour capacity, educated head of households and have lower dependency ratio. The same hold for development corridor; proximity to development

corridor is more beneficial when household have educated labour stock or own vehicles. Similarly, in terms of district roads, households are more likely to have higher assets when they are close to district roads and have a high educated labour stock or own a vehicle. These results show how differentiated household capabilities such as education, vehicles and demographic composition unlock access to improved livelihood outcomes and enable transitions into different livelihood groups.

In overall, the results indicate that the infrastructural assemblage interacts with these capabilities to produce uneven livelihood outcomes. This means that the outcomes of development corridors are highly dependent on the composition of assets and resources that households have, and that capabilities determine how these can be converted into livelihood gains reflecting selective integration and extractive enclaves.

In summary, it has become clear that development corridors can produce uneven development through three interrelated mechanisms. By conceptualising development corridors as part of an infrastructural assemblage, we can see how these three mechanisms work together to produce which form of patterns. The empirical results from the WBNLDC case fall largely into the selective integration and extractive enclaves across all three mechanisms outline in Table 1.

Spatial selectivity operates through the location and design of the corridor and determines which places and actors are integrated in to the corridor and which are left out. Along the WBNLDC, night-time lights and land use change are concentrated in logistic hubs, production sites and tourisms zones tied the global commodity chains while areas in between show little to no development. In this case, the WBNLDC selectively integrates only locations that are essential for the commodity value chains reflecting selective integrations and extractive zones and thus uneven development though spatial selectivity.

Infrastructural assemblages focus on how the development corridor interacts with existing infrastructure, such as regional roads and communal conservancies. Uneven development is produced when the spatial logics of these infrastructures are misaligned. In Zambezi region, results shows both misalignment and alignment between infrastructure. District roads intended to support agriculture are constrained by communal

conservancies that prioritise conservation objectives, which leads to competing land uses. These findings again reflect how the selective integration and extractive enclaves manifest along the corridor. However, the region also produces infrastructural alignment, e.g. when development corridors attract tourists who may generate income for conservancies, this interaction can support broader, corridor-wide integration. However such cases may be limited given that literature in Zambezi region shows that only a small percentage of income from tourism is captured in the region (Kalvelage et al., 2020).

Differentiated household capabilities determine who is able to convert improved access into livelihood improvements. Results in Zambezi Region revealed that households with limited capabilities may not benefit from proximity to infrastructure, thereby contributing to differentiated outcomes for livelihood typologies. The patterns found in this study reflect selective integration and extractive enclaves where by only better off households with better education and higher assets are able to take advantage of improved access.

Together, these three mechanisms explain how the WBNLDC can produce different outcomes across space and households reflecting selective integration and extractive enclaves, rather than corridor-wide integration and agglomeration.

7.2 Conceptual Contributions

This dissertation examines the development corridors produce uneven development. It is situated within a broader debates in economic geography and infrastructure-led development that treats corridors as territorial projects which selectively reorganise space, access, and mobility in ways that extend state and corporate power across regions (Dannenberg et al., 2018; Schindler & Kanai, 2021; Scholvin, 2021). Building on both neoclassical foundations of mainstream infrastructure-led development and critical political economy literature, it contributes both empirically and conceptually.

Firstly, the outcomes in respect to regional development are poorly understood and literature argues that development corridors lead to uneven development. However, in this dissertation I argue that there is a lack of analytical frameworks and empirical work that clearly link corridors to their actual developmental outcomes. To address this, this dissertation makes an empirical contribution by offering a cross-scalar empirical approach comprising of NTL data, land use change data, and household survey data with proximity measures to study the outcomes of development corridors. This method is particularly helpful in African contexts where reliable data is scarce or mostly aggregated at higher administrative levels which makes it less useful for comparative studies (Storeygard, 2016). This rich methodology allows for cross-border and historical comparisons which offers a way to track how infrastructure-led development develops over time and is essential for development corridors that span multiple countries and decades.

Second, the dissertation develops an analytical framework for interpreting spatial development outcomes along corridors. (Ferguson, 2006). This framework distinguishes the corridor outcome into two types a) integration and agglomeration and b) selective integration and extractive enclaves. Building on a neoclassical mechanism which expects that infrastructure investment will lead to corridor-wide growth (World Bank, 2009) or from a political economy perspective which critiques infrastructure that such investment instead reproduces selective integration and extractive enclaves while generating limited benefits for the intermediate regions. This framework makes the distinctions of the outcomes of economic activity depending on the observed patterns and mechanisms present. This framework can make it easier to analyse and interpret developmental

outcomes according to the degree of spatial selectivity, infrastructural alignment and capabilities observed in a development corridor and in work beyond this dissertation.

Third this dissertation conceptualises development corridors as part of a wider infrastructural assemblage comprising development corridors, regional roads and communal conservancies, whose interactions shape livelihood outcomes. This perspective draws from a body of existing scholarship that demonstrates infrastructure to be not only material and technical in nature, but also social and political (Hansen & Schulze, 2021; Hudalah, 2026; Kanoi et al., 2022). The design and utilisation of infrastructure is shaped by the actors involved in its governance and use, as well as the regulatory frameworks that determine the distribution of benefits and the exclusion of certain groups (Bollig & Krause, 2023; Kanoi et al., 2022). In this sense, infrastructure is never neutral, it reflects particular interests and relations of power, and can function as a public good, but also as a tool of control and exclusion. This framework provides foundation for understanding that the outcomes of infrastructure-led development emerge through the interaction of other existing infrastructural and institutional arrangements (Barry, 2020; Hansen & Schulze, 2021)

This framework is particularly important in Southern Africa, where development corridors territorialise landscapes already consisting of other regimes such as regional roads and community-based conservancies (Bollig & Krause, 2023; Kalvelage et al., 2021; Kioko & Changwony, 2025). They are all territorial infrastructures with their own spatial logics and rules for future making aiming to shape livelihoods, land use and movement. The dissertation thus recommends an understanding of infrastructure in relational terms, as part of a broader infrastructural assemblage, in which material features, institutions and political decisions collectively determine access, mobility, land use and livelihoods. This conceptualisation shifts the unit of analysis from the corridor itself to the relations between infrastructures. Within this conceptualisation, the development corridor is viewed as a politically and economically embedded spatial tool that reorganises space and access, and in doing so shaping livelihoods. This dissertation therefore moves away from studying spatial planning policies in isolation, recommending a place-based, multi-scalar

approach that considers the wider landscape when analysing regional development and uneven development around development corridors.

Fourth, the dissertation calls for an understanding of the outcomes of development corridors as shaped both by existing infrastructure and by household capabilities. Mainstream infrastructure-led development tends to assume that once connectivity is established, regions will develop automatically, treating access as the main prerequisite for development (World Bank, 2009). However, this dissertation focused on household level revealed that infrastructure is experienced differently based on household capabilities. Therefore, conceptually this means that infrastructural assemblage should be considered together with capabilities as households differs in their ability to convert the access into livelihoods (Dorward et al., 2009). By combining infrastructural assemblage with capabilities approach, it became clear that infrastructure is only one part of the equation and capabilities matter more in explain why uneven development is experience in regions along the corridor.

Together, these contributions support a place-based conceptualisation of development corridors that takes into account existing territorial infrastructure and household capabilities, and offers a multi-scalar approach to understanding the mechanisms behind uneven development around development corridors. The results emphasise that the outcomes of infrastructure-led development are not only shaped by connectivity but by spatial selectivity, interactions with other infrastructure and the differentiated capabilities of households.

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7.3 Policy Implications

Development corridors are widely promoted as drivers of economic growth in Africa. The findings of this dissertation however supports critical concerns that corridors often lead to unequitable economic growth, instead they mainly function as tools for commodities circulation, moving goods into global value chains without generating wider regional development (Dannenberg et al., 2018; Enns, 2018; Scholvin, 2021). Economic activities and land use transformation in this dissertation remained concentrated in selected nodes, infrastructural assemblages create both complementarities and conflicts and access to improved access is mediated by household capabilities. The following policy implications can be derived from these results.

At corridor level basis, the results show that spatial selectivity is a feature of infrastructure-led development. Economic activity along the WBNLDC have been found to be highly concentrated at production sites and logistics hubs while leaving the areas in between empty. Policy should therefore move away from the assumption that corridor-wide benefit will automatically spread along the corridor. Instead, planning should therefore ensure the left behind places are given specific measures to ensure the benefits are realised. These policies are necessary to avoid risking reinforcing existing spatial inequalities (Hartmann et al., 2021). The following recommendations are examples of how planning could move corridors away from uneven development to the expected corridor wide agglomeration and integration.

First, the nation states involved in creating of these cross-border corridors need to ensure the planning is rooted into existing political and institutional structures in a way that support regional development. The corridor-wide analysis in this dissertation showed that land-use dynamics and conflicts are a central issue, especially where the corridor passes through areas with competing land uses, such as conservation and agriculture. These conflicts do not on their own determine the developmental outcomes, but they strongly shape the conditions under which agricultural intensification or economic diversification can take place. There is therefore a need for national and regional authorities to strategically plan corridor routes that are in alignment with the expected developmental

goals. This includes, ensuring that the location of the corridor and its key nodes is compatible with the types of investment that are foreseen: for example, if the corridor is expected to support agricultural development, it needs to intersect areas with suitable soils and water; if tourism is the focus, there must be attractions and services that can realistically be developed. This requires clear institutional responsibilities for land-use decisions and zoning along the corridor, so that potential conflicts between conservation, agriculture and other uses are planned for transparently rather than becoming a source of ongoing conflict.

An example of such institutional planning and coordination is the Zambezi Region and the WBNLDC. The corridor passes through one of Africa's largest transfrontier conservation areas (KAZA), while at the same time there are various communal conservancies, community forests and national parks, each with different land-use plans within their boundaries. In addition, ministries under the Namibian government including the Ministry of Agriculture, Fisheries, Water and Land Reform, Ministry of Urban and Rural Development and on the other side of the border, Zambian ministries including Ministry of Energy and Water Development and Ministry of Agriculture and Cooperatives, operate alongside communal conservancies and other local institutions, including traditional authorities and local communities. In cases like this, planning needs to consider all those stakeholders within the region to ensure that the expected regional development goals are achieved. Such coordinated efforts would help avoid the challenges currently documented along the corridor, including the exclusion of traditional authorities from corridor planning (Kadhikwa et al., 2026) and the "connectivity patchwork" described by Zajontz (Zajontz, 2024).

Second, the dissertation showed that development corridors interact with regional and district roads and communal conservancies in ways that can either reinforce or undermine each other's development goals. Policy makers should therefore treat development corridors as part of a wider infrastructural assemblage, made out of hard and soft infrastructures, rather than as isolated projects (Barry, 2020; Hudalah, 2026; Larkin, 2013). This means planning corridor development should involve ongoing work of relations through which corridors and existing infrastructure such as roads, conservancies

or knowledge systems can support, rather than contradict, each other in specific places (Barry, 2020; Hansen & Schulze, 2021). This reflects why it is important to strategical plan for alignments instead of misalignment among existing strategies. This recommendation is in agreement with recommendations to look beyond territorial interest of state in order to provide useful framework through which multiple local and trans local interests can be negotiated within the unevenness of space

Finally, the household-level analysis shows that the outcomes of infrastructural assemblages are shaped by household capabilities. However, proximity to infrastructure does not automatically improve livelihoods. Rather, education, assets, labour and mobility determine whether households can exploit new access to transition into farm-market or non-farm livelihoods, or whether they remain dependent on subsistence farming and remittances. Therefore, there is a need to complement infrastructure development with differentiated support programmes. Relevant measure should be in place to support economic expectation such as agricultural expansion or tourism activities would require investments in education, vocational training or enterprise support. This requires for programmes that are adapted to the population living in each corridor region and vary by the assemblage composition such as inside vs outside conservancies and near district road vs near corridor.

Taken together, these implications support a place-based approach to understanding infrastructure-led development. The design of development corridors therefore needs to consist of an analysis of existing regional resource and how these strategies are likely to interact. New corridor policies should then be introduced in collaboration with existing strategies, with clear guidelines on how to achieve agglomeration and spill over effects in a way that is compatible with local conditions. This approach avoids assuming that infrastructure alone can deliver equitable regional development.

7.4 Future Research and Recommendations

While this dissertation provides useful contribution to the field of economic geography, it also rises important question which could not be fully addressed in this study and calls for further research.

Most African governments are increasingly aligning their development goals with infrastructure-led development, targeting and prioritising infrastructure that connects economic hubs and trade corridors, an example is the Programme for Infrastructure Development in Africa (PIDA) (Enns & Bersaglio, 2020; The PIDA, 2020). At the same time, community-based conservation areas are increasingly becoming popular all-across Southern Africa (Bollig & Krause, 2023; Hulke et al., 2020; Jones et al., 2015; Kalvelage et al., 2021). Together, these represent two distinct spatial and economic pathways. However, literature on regional economic development is concerned with questions about how new paths interact with existing regional paths termed as path formation and path interdependencies (Gauna Ruiz de León et al., 2026; Sloan et al., 2019). This dissertation shows the need to conceptualise development corridors, regional roads, and conservancies are interdependent territorial development pathways. Using an assemblage theory, the empirical results show that this infrastructural assemblage produces differentiated livelihood outcomes, and their interaction in space can be complementary or conflicting. This raises broader questions about how different development pathways interact, reinforce or compete with one other. Future research should therefore evaluate the evolution of corridor-led development and other existing development strategies, in order to ascertain whether the findings of this study can be extended to other types of infrastructure, such as energy and national parks, over time.

While the use of NTL data has become increasingly prominent in economic development studies, several methodological limitations must be acknowledged. While NTL data can identify areas of economic activity changes, they cannot necessarily explain the reason behind these changes. Changes in observed radiance can originate from different sources, including mining, construction, industrial activity, settlement expansion and fires (Li et al., 2016). Furthermore, research in the African context further reveals that

increased light does not necessarily indicate local development but as observed it may also represent activities such as surface mining and industry along development corridors (Paris & Rienow, 2025). Literature also warns that NTL varies by spatial contexts particularly between densely populated urban areas and sparsely populated rural areas (Gibson et al., 2019). It is therefore recommended that future research move beyond detecting spatial changes in economic activities to characterising the sources and mechanism producing those changes. Similar to NTL, land use change analysis should be complemented with additional data to explain what the transformation means in terms of regional development. Previous studies have linked land use change along development corridors to processes such as land grabbing and dispossession (Gellert Paris & Rienow, 2023). Additional information on large-scale land acquisitions, and resettlement may also help to clarify who benefits from land-use change and how it is linked to development, as expansion does not necessarily mean that the local population has benefited. Although integration of household survey was done in this study, future research could extend the scale beyond the Zambezi Region and focus on the whole corridor. Such would allow us to distinguish whether the pattern observed in this study are central to the Zambezi Region or reflect broader corridor development process. In addition, qualitative methods could be useful used to complement the quantitative analysis done on NTL and LULC datasets and identify the mechanism for economic activities identified (Gallaher & WinklerPrins, 2016). Therefore, future studies could complement both NTL and land use information with qualitative research to explain the mechanisms behind spatial and economic patterns observed in this study.

This dissertation uses household survey collected in 2019 and 2023 to explain livelihood outcomes and transitions. This study period presents two important limitations for interpreting the results. Firstly, the period spans the years before and after COVID-19, making it difficult to determine whether the recorded changes reflect the reality or are primarily its aftershock. Studies in Africa show that the pandemic disrupted economies in most African countries impacting on livelihoods, especially in agriculture (Kinyondo & Pelizzo, 2021; Lendelvo et al., 2020). Therefore, it is important to differentiate the results of this study from those that may be driven by the pandemic given that the Zambezi region relies heavily on agriculture and tourism economy generated from conservancies, which

depends on increasing tourist arrivals to the region (Hulke et al., 2022). However, the closure of national borders and restrictions on international travel severely reduced tourist arrivals and disrupted tourism-related income for conservancies (Lendelvo et al., 2020). Secondly, a five-year interval is relatively short for observing meaningful transitions between household livelihood typologies. Such changes, especially shifts between subsistence, farm-market and non-farm strategies, often unfold over longer time and can be strongly influenced by temporary shocks, such as the pandemic. It is therefore important to consider whether the timeframe is too short to observe genuine improvements in capabilities, particularly given the limited training and meetings during the pandemic (Lendelvo et al., 2020). These limitations means that the livelihood outcomes should be interpreted with caution and longer-term panel data may be needed for future studies.

7.5 Conclusion

To conclude, infrastructure-led development promises to deliver broad-based development. However, this dissertation shows that it produces spatially and socially uneven development outcomes. These outcomes are driven by three mechanisms: spatial selectivity; infrastructural assemblages; and differentiated capabilities. While infrastructure-led development strategies do lead to development, this development is highly concentrated in specific hubs and nodes, reflecting strong spatial selectivity. Infrastructure-led strategies such as development corridors are introduced into spaces that are already territorialised by existing spatial planning tools and institutions. Depending on how the logics of these existing arrangements and corridor development align, they can create complementarities or conflicts, leading to differentiated livelihood outcomes. This calls for a relational understanding of infrastructure, whereby new infrastructure is introduced in coordination with existing infrastructure to ensure that their spatial logics and functions align. In addition, access to infrastructure is mediated by household capabilities, determining how this access can be converted into livelihood gains. The study findings suggest the need to move beyond treating infrastructure-led strategies in isolation, instead they must be understood relationally with other infrastructure and household capabilities to produce corridor-wide integration and agglomeration.

8 References

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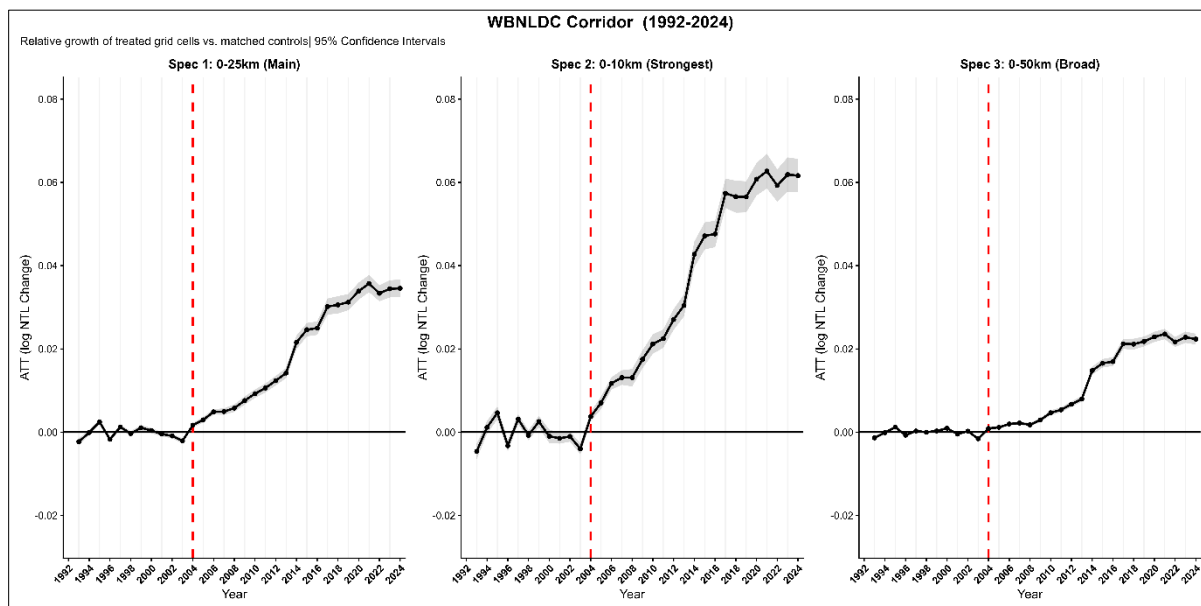
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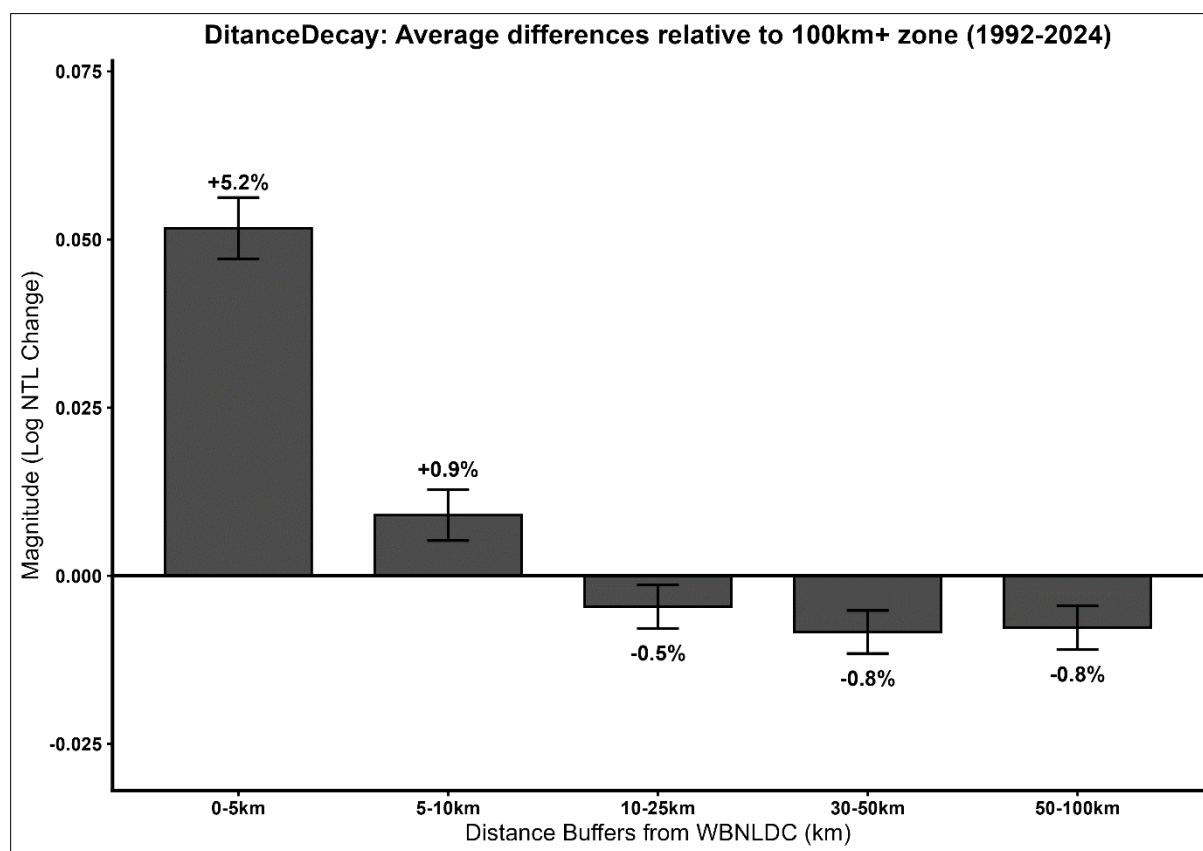
9 Appendix

Appendix A: Supplementary Material

Appendix A.1: Event-study robustness across buffer specifications (0-10km, 0-25km, 0-50km). Source: Authors' own calculations



Appendix A.2: Spatial decay of NTL intensity by distance buffers. Source: Authors' own calculations



A.3 Sensitivity Analysis of estimates to buffer specifications. Source: Authors' own calculations

Specification	TWFE ATT	Callaway AT	No of Observations
Spec 1 (0-25km)	0.018	0.0193	8372232
Spec 2 (0-10km)	0.0347	0.0379	3351282
Spec 3 (0-50km)	0.0119	0.0121	14983518

Appendix A.4: Overall event-study estimates. Source: Authors' own calculations

Event time	Coefficient se
Year -11	-0.000 (0.000)
Year -10	-0.001** (0.000)
Year -9	-0.002*** (0.000)
Year -8	0.001 (0.000)
Year -7	-0.001** (0.000)
Year -6	-0.000 (0.000)
Year -5	-0.000 (0.000)
Year -4	0.001* (0.000)
Year -3	0.001* (0.000)
Year -2	0.001* (0.000)
Year 0 (Treatment)	-0.002*** (0.000)
Year +1	-0.000 (0.000)
Year +2	0.001 (0.000)
Year +3	0.002*** (0.000)
Year +4	0.003*** (0.000)
Year +5	0.004*** (0.000)
Year +6	0.006*** (0.000)
Year +7	0.007*** (0.001)
Year +8	0.009*** (0.001)
Year +9	0.010*** (0.001)
Year +10	0.012*** (0.001)
Year +11	0.019*** (0.001)
Year +12	0.022*** (0.001)
Year +13	0.022*** (0.001)
Year +14	0.028*** (0.001)
Year +15	0.028*** (0.001)
Year +16	0.029*** (0.001)
Year +17	0.032*** (0.001)
Year +18	0.034*** (0.001)
Year +19	0.032*** (0.001)
Year +20	0.032*** (0.001)
Year +21	0.033*** (0.001)
Observations	7,748,202
R-squared (Overall)	0.783
RMSE	0.126

Appendix A.5: Complete country-specific event study estimates (1992-2024).

Source: Authors' own calculations

Event Time	**Namibia**	**Zambia**	**Dem. Rep. Congo**
Year -11	-0.000	-0.004***	-0.008**
Year -10	0.000	-0.001	-0.001
Year -9	0.001***	0.004***	0.002*
Year -8	-0.002***	-0.002**	0.004***
Year -7	0.001***	0.002**	0.000
Year -6	-0.000	-0.001*	0.006***
Year -5	-0.001***	0.003***	0.007***
Year -4	0.001***	-0.001	0.001
Year -3	-0.001***	0.000	0.001
Year -2	0.001**	-0.003***	-0.001
Year -1	-0.001***	-0.003***	-0.005***
Year 0 (Treatment)	0.001***	0.003***	-0.002
Year +1	0.002***	0.005***	-0.000
Year +2	0.002***	0.008***	0.007***
Year +3	0.002***	0.009***	0.007***
Year +4	0.002***	0.009***	0.014***
Year +5	0.003***	0.012***	0.018***
Year +6	0.003***	0.013***	0.035***
Year +7	0.005***	0.014***	0.034***
Year +8	0.004***	0.018***	0.043***
Year +9	0.006***	0.020***	0.045***
Year +10	0.010***	0.030***	0.058***
Year +11	0.012***	0.033***	0.069***
Year +12	0.012***	0.034***	0.072***
Year +13	0.015***	0.040***	0.089***
Year +14	0.015***	0.040***	0.098***
Year +15	0.013***	0.042***	0.113***
Year +16	0.014***	0.044***	0.129***
Year +17	0.015***	0.048***	0.130***
Year +18	0.013***	0.045***	0.130***
Year +19	0.011***	0.048***	0.132***
Year +20	0.012***	0.047***	0.141***

***p < 0.05, **p < 0.01, ***p < 0.001 Full timeline :1992 (Year -12) to 2024 (Year +20). Standard errors in parentheses. 1km×1km grid FEs. PSM weights. Clustered SEs.**

Appendix A.6 Variables used in PCA creation

Index Variable /	Variable	Data type	Information captured
Asset	Durable good	Binary	Ownership of: Radio, television, fridge, mobile phone, laptop/computer.
	Housing Quality	Categorical	Primary materials used for floors (h03), roofs (h06), and walls (h05).
	Utility Access	Categorical	Main source of energy for lighting (h09) and cooking (h11).
Land	Natural capital	Numeric	Total plot size (Ind01), area cleared (Ind02/f03), area for crops (Ind03) and grazing (Ind04).
	Productive potential	Categorical	Land classification (Ind_07), primary activity (f01), and specific clearing binary flags (f04)
Social capital	Institutional/Social	ordinal	Organisational memberships (as18), informal financial access (as12/13), and network influence (as07).
	Trust	ordinal	Level of trust in community members and local institutional leadership (trst04/05)
Income	Financial activities	Aggregate Numeric	Sum of income from formal employment, informal employment, on-farm income, and off-farm income, pensions and remittances, minus total productive expenditure divided by household size.

Appendix A.7: Robustness and Coefficient Stability Checks

	Baseline Random Effects	Fixed Effects	Drop Richest 5%	Spatial restriction: Drop Near 10%	No Livelihood Diversification
Dist. Corridor (log min)	0.044 (0.096)	-0.607 (0.629)	0.063 (0.099)	0.131 (0.111)	0.233** (0.106)
Dist. District Road (log min)	-0.108 (0.117)	-0.108 (0.442)	-0.150 (0.119)	-0.098 (0.121)	-0.174 (0.131)
HCI: Leadership	-0.547*** (0.102)		-0.643*** (0.104)	-0.538*** (0.108)	-0.424*** (0.113)
Vehicle Ownership	0.801** (0.373)	-0.317 (0.625)	0.009 (0.416)	0.826** (0.403)	1.176*** (0.422)
Inside Conservancy	0.290 (0.216)	0.851 (2.165)	0.277 (0.220)	0.321 (0.227)	0.289 (0.242)
Livelihood Diversification	2.043*** (0.147)	2.037*** (0.149)	2.021*** (0.150)	2.017*** (0.155)	
Household Size	-0.159*** (0.039)	- 0.191*** (0.062)	-0.117*** (0.039)	-0.170*** (0.041)	-0.106** (0.044)
Year: 2023	0.141 (0.175)	0.118 (0.176)	0.108 (0.179)	0.059 (0.186)	-0.706*** (0.191)
Num.Obs.	1096	1096	1041	986	1096
R2	0.266	0.287	0.257	0.271	0.043

* p < 0.1, ** p < 0.05, *** p < 0.01. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively

Note: Infrastructure variables are measured as spatial time, thus lower value indicates shorter travel times and better access. Negative coefficients should therefore be interpreted as the better accessibility the higher the outcomes as vice versa.

Appendix B: Own Contribution

All three manuscripts (Chapters 4, 5 and 6) were co-authored with the supervisors of this dissertation. Chapter 4 was co-authored with Prof. Dr. Javier Revilla Diez (primary supervisor and Principal Investigator of the C01 Future in Chains project), Prof. Dr. Georg Bareth (co-supervisor), and Dr. Christoph Hutt (advisor) at the University of Cologne. Chapters 5 and 6 were co-authored with Prof. Dr. Javier Revilla Diez.

I have contributed to these articles in the following ways:

- Review of relevant literature
- Development of conceptual framework for all three papers
- Development of Research design
- Selection of research methods
- Design of data analysis methods
- Acquisition and collection of data for Chapters 4 and 5
- Data cleaning and processing for all datasets
- Data analysis and verification using software such as ArcGIS Pro, RStudio, Google Earth Engine and Google Earth
- Independent writing of the papers
- Presentation of results in the forms of tables, maps and figures
- Revision of all manuscripts and conceptual frameworks under the guidance of Prof. Dr. Javier Revilla Diez