

## Impacts of emerging infrastructure development on wildlife species and habitats in Tanzania

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### Abstract

The loss of wildlife species due to habitat deterioration and pollution represents a major threat to biodiversity conservation. This is compounded by the rapid development of infrastructure i.e., expansion of roads, railways, harbours, construction of industries, human settlements and agricultural infrastructure. A few studies have explored the significant effects of emerging infrastructure development on wildlife species and habitats particularly in developing countries like Tanzania. We reviewed 58 research articles and reports, to highlight the significant impacts of emerging infrastructure on both aquatic and terrestrial species and habitats in Tanzania. We show that despite the role it plays in the development, the infrastructure contributes significantly to the loss of wildlife species. For instance, habitat loss, edge effects, population isolation, road mortality, and increased human access are among the effects of highways across the Serengeti, Mikumi, and Katavi National Parks in Tanzania. Effects on the health of aquatic species, pollution and loss of habitat have been pointed out as impacts due to the construction of hotels and industries upstream and along the coasts, expansion of harbours and agricultural activities. Environment effects i.e., reduction of forest, ecosystem services, and riverine habitat, and loss of species are anticipated due to the construction of Stiegler's Gorge Hydroelectric Dam, across the Rufiji River in eastern Tanzania. Though infrastructure development undoubtedly offers opportunities to boost economic growth and reduce poverty in developing nations, it should be planned to have the least possible negative effects on biodiversity. Well-planned infrastructure development could lessen human pressure on wildlife species and habitats. This paper would be useful to policymakers and politicians in developing nations to avoid the implementation of infrastructure development in biodiversity-rich or protected areas as their decision may jeopardize the integrity of wildlife species and future generations.

**Keywords:** Biodiversity, Conservation, Habitat loss, Human development, Road mortality

## Introduction

The loss of wildlife species due to habitat loss, degradation, and fragmentation represents the main threat to biodiversity conservation (Laurance et al., 2014; Laurance & Arrea, 2017; Lechner et al., 2018). This is strongly related to infrastructure (i.e., roads, railways, irrigation canals, powerlines, pipelines, and human settlements) development (Laurance et al., 2014; Sharma et al., 2018). The global increase in population and economic growth fuelled by globalization accelerates the development of infrastructure (Wang et al., 2022). An expanding population calls for contemporary infrastructure to enhance food production, transportation, industry modernization, and the diversification of energy sources (Wang et al., 2022). Although infrastructure development is a crucial component of economic growth, it is also acknowledged as one of the major causes of biodiversity loss worldwide (Helldin, 2019; Hopcraft et al., 2015; Torres et al., 2016). It is considered detrimental to the conservation of wildlife species, habitats, and ecosystem services and can also affect people who depend on biodiversity resources for their livelihoods (Benítez-López et al., 2010; Hopcraft et al., 2015; Sharma et al., 2018). Some of the detrimental effects of infrastructure development on wildlife are presented in Table 1.

**Table 1.** Negative impact of infrastructure development (roads, railways, irrigation canals, powerlines, pipelines, and human settlements) on terrestrial wildlife species and habitats

Negative impacts on wildlife species and habitats	References
Degradation and fragmentation of wildlife habitats	(Helldin, 2019; Torres et al., 2016)
Creation of physical barriers, restrict wildlife movements around the infrastructure	(Helldin, 2019; Newmark et al., 1996; Torres et al., 2016)
Increase mortality rates, traffic casualties, and stress wildlife species	(Helldin, 2019; Newmark et al., 1996; Torres et al., 2016)
Disturbance by noise, light and other visual cues	(Helldin, 2019; Newmark et al., 1996)
Chemical pollution, spread of dust, and alien species	(Caro et al., 2014; Newmark et al., 1996)
Changes in hydrology and microclimate and accidents	(Helldin, 2019; Laurance et al. 2014:)
Increased human access to protected areas, land clearing and wildlife hunting	(Laurance et al. 2014; Newmark et al., 1996; Sharma et al. 2018)
Adverse impact on the viability and population levels wildlife species	(Sharma et al., 2018)
Road networks cause extensive loss and ecosystem fragmentation	(Şakar et al., 2022; Sharma et al., 2018; Tarir et al., 2017; Wang et al., 2022)
Roadkill, barrier effects, population endangerment, and extinction.	(Benítez-López et al., 2010; Wang et al., 2022)

According to earlier research, there are more than 29 million kilometers of roads in the world, which have fragmented the terrestrial ecosystems into over 600,000 patches, posing major threats to wildlife species and ecological stability (Ibisch et al., 2016; Wang et al., 2022). Furthermore, by

2050, it is predicted that there will be at least 25 million kilometers of new roads built worldwide, significantly increasing both the number and extent of highways (Laurance et al., 2014). Thus, such an expansion of infrastructure networks, and a rise in the global population in the ensuing decades would further increase pressure on survival of wildlife species and habitat integrity (Sharma et al., 2018; Torres et al., 2016). In the tropics and subtropics, the percentage of highways or main roads crossing terrestrial NPs have been increasing (Andersen & Jang, 2021; Caro et al., 2014; Lechner et al., 2018). According to a study by Caro et al. (2014), nearly a fifth of the 373 national parks in 58 tropical and subtropical countries are traversed by one or more main roads, and one in twelve is by highways, with protected areas in Asia suffering significantly (Table 2).

**Table 2.** Percentage of terrestrial NPs in the tropics and subtropics that cross one or more highways (now either in use or under construction) or main roads (data from Satellite World Atlas, 2004–2006). Source: Caro et al. (2014).

Region	Number of		Percentage of NPs traversed by	
	NPs	Countries	Highways	Main roads
Africa	152	33	8.6	27.8
Asia	36	6	10.8	49.7
Australasia	33	1	6.1	24.2
Caribbean	7	4	12.5	0
Central America	29	4	6.3	8.7
South America	116	10	5.9	21.1
Totals and means	373	58	8.4	21.9

Although Sustainable Development Goals e.g. SDG 9 (industry, innovation and infrastructure) calls for resilient infrastructure and promote sustainable industrialization, the majority of these infrastructures are in developing nations with exceptional biodiversity and vital ecosystem services (Helldin, 2019; Sharma et al., 2018; Torres et al., 2016). Laurance et al. (2014) report that about 90% of all new infrastructure is built in developing nations, mostly tropical and subtropical countries that have the most diverse ecosystems. For instance, new roads are cutting through wilderness regions like the Amazon and the Congo Basin (Laurance et al., 2014; Laurance & Arrea, 2017). Large infrastructure projects are being planned throughout Asia, including the Chinese initiative One Belt, One Road (Andersen & Jang, 2021; Lechner et al., 2018), and Stiegler's Gorge Dam across the Rufiji River in eastern Tanzania are within or passes through significant regional biodiversity hotspots (Kruitwagen et al., 2008).

If these infrastructures are not in line with the 2030 Agenda for Sustainable Development which emphasise the balance across economic, social and environmental dimensions, they could threaten

wildlife species and habitats (Laurance et al., 2014; Laurance & Arrea, 2017). Infrastructure, such as roads, rails, transmission lines, and dams that aid in the extraction of oil, gas, metals, and other valuable natural resources within or near wildlife or biodiversity-rich areas, for example, causes significant environmental harm (Caro et al., 2014; Şakar et al., 2022; Wang et al., 2022). Most involve disrupting wildlife migration routes, draining freshwater resources, eroding or polluting the soil, and fragmenting and destroying forests, ecosystem services, and other natural habitats. Unfortunately, the significant effects of these projects on wildlife species and habitats remain generally overlooked, mostly in developing countries such as Tanzania (Caro, 2015; Caro et al., 2014). Tanzania is one of East African nations with roads crossing protected areas. For example, a highway that connects the regions of Manyara and Mara in Serengeti National Park, Morogoro and Iringa in Mikumi National Park, and Rukwa and Katavi in Katavi National Park (Hopcraft et al. 2015; Caro et al. 2014). In eastern Tanzania, work is currently underway to build the Stiegler's Gorge Hydroelectric Dam across the Rufiji River (Andrew 2021, Rosen 2022). Yet, Tanzania is still in the preliminary stages of researching how wildlife species are affected by and interact with emerging infrastructure. To safeguard wildlife species and their habitats amid planned infrastructure development in Tanzania, we reviewed and benchmarked current research conducted elsewhere, and suggested development paths and strategies. We assessed the impact of infrastructure development on aquatic and terrestrial wildlife species, as well as the integrity of the United Nations Sustainable Development Goals in terms of wildlife conservation in the country.

## **Material and methods**

Information about the impact of emerging infrastructure on animal species was obtained by reviewing published research articles and reports from Tanzania and worldwide. Reviewed articles, reports, and news are those that point out the impacts of infrastructure development in terrestrial and aquatic environments. These articles focused on roads, human settlements, small- and large-scale agriculture, powerlines, pipelines, railways, and harbours. Moreover, reports included in this review included Environmental Impact Assessment and Environmental Audit reports and reports from conservation agencies. Peer-reviewed articles were retrieved from international databases such as Springer, Elsevier, SAGE, ResearchGate, Scopus, Wiley-Blackwell, PLOS One, and the Web of Science as well as Tanzanian journals. We specifically looked for the words “road,” “impact,” “infrastructure,” “highway,” “human settlements,” “railway,” and “wildlife,” “amphibia,” “reptile,” “biodiversity,” “aquatic environment”, "mammal," and "bird," in the keywords and titles of the articles (Benítez-López et al., 2010; Wang et al., 2022).

### State of protected and conserved areas

The United Republic of Tanzania (6.3690° S, 34.8888° E) has a total area of 945,087 km<sup>2</sup>. It is one of the four world's mega-biodiversity-rich nations (Table 3, Caro et al., 2014; Gizachew et al., 2020), home to over 14,500 recognized species (Kideghesho et al., 2006; URT, 2014). The country has 840 conserved or protected areas that cover approximately 361,594 km<sup>2</sup> and 7,330 km<sup>2</sup> of the land and ocean, respectively (IUCN, 2020; Kegamba et al., 2022). National Parks (NP), Game Reserves (GR), Game Controlled (GC) areas, Nature Reserves (NR), Forest Reserves (FR), and Forest Plantations (FP), Ngorongoro Conservation Area (NCA), and Wildlife Management Areas (WMAs) are the main types of protected areas in the country (Gizachew et al., 2020; Kegamba et al., 2022). It is one of the top 25 countries for endemic and threatened species, and it is home to six of the 25 recognised biodiversity hotspots (Kideghesho et al., 2021; URT, 2014). After Madagascar, this nation hosts the second-highest number of IUCN Red List of threatened species in Africa, and it is ranked seventh internationally. There are more than 10,000 plant species in Tanzania, 1,100 of which are indigenous (Kideghesho et al., 2021; URT, 2014). Tanzania, followed by South Africa, outperforms the other 11 Southern Africa Development Co-operation (SADC) member countries in the sub-Saharan region in terms of the number of vertebrates and high endemism (J. Kideghesho et al., 2013). The country also possesses more than 74% of all plants found in East Africa (Kideghesho et al., 2013). A quarter of Tanzania's total plant species have medicinal properties that can be used to treat and prevent a wide range of illnesses. Essentially, 60% of Tanzania's population relies on medicinal plants for all of their basic medical needs (Hilonga et al., 2019; Kideghesho et al., 2021; URT, 2014). Even though Tanzania has a high biodiversity that contributes significantly to economic development and bettering people's livelihoods, the country's expanding infrastructural development threatens wildlife species and habitats (Kideghesho et al., 2006; Kisanga et al., 2019; Newmark et al., 1996).

Table 3. Protected areas coverage, designated as global sites of importance in Tanzania (IUCN, 2020)

Type of protected area	Area protected or conserved
Terrestrial and inland water	54.60%
Coastal and marine	6.50%
Global designation	Number of sites
UNESCO Man and Biosphere Reserves	5
UNESCO World Heritage Sites (natural or mixed)	4
Wetlands of International Importance (Ramsar site)	4

## **Impact of infrastructure on terrestrial wildlife species**

The that habitat loss and degradation associated with infrastructure development such as roads are the primary causes of the decline and extinction of wildlife species in terrestrial ecosystems (Caro, 2015; Caro et al., 2014; Leweri & Ojija, 2018; Tarimo et al., 2017; Torres et al., 2016). Besides habitat loss, degradation, fragmentation, and barrier effects, development infrastructure, for instance, highways (paved or unpaved roads), increases the mortality of species, i.e., due to road kills (Caro, 2015; Caro et al., 2014; Newmark et al., 1996; Walelign et al., 2019). Most of the species tend to avoid areas around such infrastructures, and thus, their population densities are also lower (Helldin, 2019; Newmark et al., 1996). Previous quantitative studies on the effects of road infrastructure on wildlife species has been carried out either inside or outside protected areas in Tanzania (Caro, 2015; Hopcraft et al., 2015; Kisanga et al., 2019; Newmark et al., 1996; Walelign et al., 2019). These studies suggest that wildlife species especially large mammals are in grave danger due to a history of high mortality rates (Box 1)

### **Evidence from Mikumi National Park**

Foot surveys carried out in Mikumi National Park in 1988, 1989, 1991, and 1992 along a major trans-national highway that bisects the park revealed that the feeding habits of wildlife, for instance, eland, bohor reedbuck, black-backed jackal, elephant, zebra, and wildebeest, had been significantly impacted. For instance, their grazing and browsing rate in areas near the highway has decreased, and they rarely use these areas more than expected within 200 to 600 m of the highway (Newmark et al. 1996). Large mammal highway fatalities in the park are high; for instance, there were 456 large mammal highway fatalities reported (Newmark et al. 1996). The number of highway road fatalities was highly connected with carnivore species (Kisanga et al. 2019; Newmark et al., 1996). Another study examining how Mikumi National Park's various linear infrastructures affected the diversity of small animals discovered that the level of disruption brought on by the infrastructure decreased the quantity of small mammals (Kisanga et al. 2019).

In Tanzania, some existing paved or unpaved roads provide access to towns and major cities passing through protected areas. For instance, the road that crosses Serengeti NP connects Mara and Manyara regions; that passes through Mikumi NP connects Morogoro and Iringa regions; and that crossing Katavi NP connects Katavi and Rukwa regions (Caro, 2015; Kisanga et al., 2019; Newmark et al., 1996). Traffic fatalities, physical barriers, disturbance by light, noise, and other visual cues; the spread of chemicals, litter, dust, and alien species; modifications of microclimates; and unintentional oil spills are just a few ways that roads affect wildlife species in Tanzania (Caro, 2015; Hopcraft et al., 2015; Newmark et al., 1996; Walelign et al., 2019). These effects are widely

recognized in the Mikumi NP, where road is tarmacked, and many large mammals are killed (Caro, 2015; Newmark et al., 1996).

For a number of years, speed bumps have been placed along the road in Mikumi NP to prevent traffic speed, although they have had only sporadic success in slowing down fast-moving heavier lorries and buses. Traffic still travels at 80 to 100 kph, exceeding the 70 kph that the Tanzania National Parks Authority (TANAPA) requires. Also, Mikumi NP has trash or litter on both sides of the road that can be seen for up to 40 meters. Heavy fines for hitting several mammal species have been posted on road signs (Fig 1), but compliance is rarely pursued. Compared to a tarmac road in Mikumi NP, untarmacked roads passing through Serengeti and Katavi NPs have few roadkills. Because of this, other roads, e.g. those that cross the Katavi NP and Serengeti NP, have not been upgraded to tarmac level and the plan to do so was dismissed by the government (Caro, 2015; Caro et al., 2014; Walelign et al., 2019).



**Figure 1.** Roads through Katavi and Mikumi National Parks. (a) and (b) show giraffes and lions crossing/standing on the Mikumi NP highway (Source: authors); (c) shows road construction in Katavi National Park with considerable environmental damage, (d) Mikumi NP highway used by heavy vehicles, and (e) indicates warning and fines signs for killing mammal species as drivers are entering Mikumi NP, Tanzania (Caro et al. 2014).

Increasing the amount of human infrastructure, particularly hotels, in some protected areas is also threatening wildlife species and their ecosystem integrity. The large number of hotels in the Serengeti, Arusha, Tarangire, and other national parks disrupts and curtails free wild animal

movements (Caro 2015, Kisanga et al. 2019). If the development of infrastructure continues, it will alter the ecological condition of protected areas and may lead to the loss of sensitive wildlife species (Kideghesho et al., 2006; Laurance and Arrea, 2017). Moreover, several large infrastructure projects, including new roads, dams, and railways, are being planned in Tanzania (Tarimo et al. 2017). With the launch of Wami River Bridge within the Wambi-Mbiki GR and Saadan NP wildlife corridor plus the initiation of major national construction projects, such as the Standard Gauge Railway (SGR) and the Stiegler's Gorge Hydropower Dam, the protection of rare and endangered species and ecosystem services of the threatened habitats has attracted global attention (Tarimo et al. 2017, Kisanga et al. 2019, Walelign et al. 2019). These new infrastructures could result in increased loss of wildlife species because of land clearing (Hopcraft et al. 2015; Caro et al. 2014). Besides, like other infrastructure i.e., highways crossing protected areas in Tanzania, wildlife species and habitats are likely to be impacted (e.g., roadkill and barrier effects) by the development of SGR and Stiegler's Gorge Hydropower Dam.

### **Impact of infrastructure on aquatic species and habitat**

Tanzania is blessed with a vast aquatic ecosystem that includes both inland and marine waters (Gates et al., 2021; J. Kideghesho et al., 2013). Freshwater bodies abound, comprising large lakes like Lake Victoria, Lake Tanganyika, and Lake Nyasa; significant rivers like the Wami, Rufiji, and Ruvuma; and countless smaller lakes, rivers, and dams spread throughout the nation. It also has a lengthy coastline—more than 1440 km—that borders Mozambique in the south and Kenya in the north. The coastline is home to a huge number of tiny and large islands (Ngowo et al., 2021). Numerous habitats and species of organisms are abundant in these bodies of water (Gates et al., 2021; Ibengwe et al., 2022).

Changes in the species composition, population levels, and hydrologic and geomorphic processes that form aquatic and riparian systems have all been related to infrastructure development (Gates et al., 2021; Ibengwe et al., 2022; Ngowo et al., 2021; Raycraft, 2020). In Tanzania, infrastructure development that affects aquatic environment has been connected to several different activities (Ngowo et al., 2021). For instance, the establishment of small- and large-scale agriculture, where contamination and sedimentation of downstream aquatic environments have been affecting the ecosystem and its aquatic organisms (Nchimbi et al., 2022) as has been the case for lake Rukwa in the Southern Tanzania which has resulted in the depletion of depth and loss of fish species (Mapenzi et al. 2019).

In addition, uncontrolled urbanization resulting in establishment of industries and settlement near sensitive areas (lakes and rivers) and failure to adequately manage wastewater, for instance, has



impacted aquatic environment in various ways (Trombulak and Frissell 2000). For example, contamination of water bodies such as the Msimbazi River (Dar es Salaam), Lake Victoria, Themí River (Arusha), Karanga River (Moshi), and Lake Rukwa has led to a significant loss of habitat and impaired fish health (Nchimbi et al., 2022). Industries emit chemicals, heavy metals and other untreated wastes and effluent into the valley. Whereas settlements located in the area emit substantial amount of organic waste from pit latrines and domestic waste, some of these emissions are directed towards the Msimbazi River, which makes the water in the valley very dangerous for aquatic organisms (De Wolf et al. 2001, Kruitwagen et al. 2008, Gates et al. 2021, Ngowo et al. 2021).

Furthermore, the construction of gold mining industries along the river Rukwa has been reported to pollute the river and the lake Rukwa with heavy metals such as mercury (Mapenzi et al. 2019), resulting in siltation, a decrease in lake depth, the death of species, and pollution of aquatic ecosystems (Elisa et al., 2021; Shitima & Suykens, 2023). Hotels are constructed along the coasts of the Indian Ocean and major lakes, some of which direct untreated waste or effluent into these ecosystems. Some are transported by a network of rivers towards the coast. The resulting pollution (e.g., heavy metals from these waters and effluent) can alter the ecosystem's physical-chemical parameters, leading to the death of aquatic organisms or relocating them further from their home range (Daudi et al., 2012; De Wolf et al., 2001). The most threatened ecosystem along the coast is mangroves and those species living in this ecosystem (De Wolf et al., 2001; Kruitwagen et al., 2008). A study conducted in mangrove sites in Dar es Salaam found high levels of heavy metals in sediments and their associated effects on periwinkle, *Littoraria scabra* (Mollusca: Gastropoda) (De Wolf et al., 2001), and densities of benthic communities (Daudi et al., 2012). However, it should be noted that not all pollution comes from these hotels; some comes from other sources, such as industries.

Furthermore, construction and expansion of harbours have been reported to impact the marine environment in the following ways: for example, the expansion of Dar es Salaam Harbour has been reported to result in the following negative environmental impacts: Changes in marine water quality due to the potential release of chemicals and heavy metals while dredging or backfilling; marine pollution due to the disposal of dredged materials; an increase in invasive species from increased shipping traffic; and increased marine pollution from the improper disposal of waste from marine vessels Accidental spills of oils (Daudi et al., 2012; De Wolf et al., 2001).

**Impact of energy infrastructure development e.g. mining, wind turbines, hydroelectric power, dams**

Human population growth and growing per capita consumption are causing an increasing energy demand to support industrial and domestic activities (Sarakikya et al. 2015). Therefore, efforts have been devoted to the development of different sectors of energy, including longstanding sources such as hydroelectric infrastructure and more recent technologies such as wind farms and solar plants (Sarakikya et al. 2015, Jose et al. 2016). Tanzania has a lot of energy sources, such as biomass, solar, hydropower, geothermal, biogas, wind, tidal, and waves, yet the major sources of power are natural gas, petroleum, and hydropower. These energy developments aim to provide humans with sustainable resources (Dincer 2000); however, they may also cause detrimental effects that strongly impact wildlife and their habitat. Energy developments have the potential to jeopardize biodiversity by increasing the extinction rates of endangered species (Hooper et al. 2012). The drilling for gas and petroleum products has been shown to influence patterns of communication for marine mammals, thus exposing them to externalities. Overall, activities (i.e., site preparation, assessment, vegetation removal, and the construction of roads) involved in the implementation of energy infrastructures typically have a significant impact on the landscape and biodiversity. Nevertheless, it must be understood that the magnitude of the impacts depends on the size and scope of the project itself.

**Hydroelectric production infrastructures**

Hydroelectricity refers to the electric energy generated by the movement of water through turbines. It is constructed in water reserves and often requires damming a river to simultaneously ensure the availability of water and provide the water jump necessary to move the turbines. Worldwide, there are almost 10,000 large dams (height >15 m) devoted to hydroelectric production, constituting almost 20 % of all built dams (Sánchez-Zapata et al. 2016). Currently, hydropower constitutes over 45% of the total power generated in Tanzania (Sarakikya et al. 2015, World Bank 2019). Hydroelectric production has ecological impacts on aquatic systems and their biota (Trombulak and Frissell 2000). Many of these are related to the presence of hydropower dams (Holmquist et al. 1998, Niebuhr 2022).

Dams constitute impassable barriers for the movement of most strictly aquatic animals (Holmquist et al. 1998, Niebuhr 2022). The fragmentation of river networks by dams has led to the collapse of migratory fish populations in many areas of the world (e.g. Holmquist et al. 1998, Limburg and Waldman 2009, Hall et al. 2012). A search in the IUCN red list ([www.iucnredlist.org](http://www.iucnredlist.org)) provides a list of 452 threatened fish species that are negatively affected by dams (threats 7.2.9, 7.2.10 or 7.2.11

in the IUCN threat classification), including 85 critically endangered and 8 extinct taxa. These numbers underestimate the real number of fish species affected by dams, because fish species have not been globally assessed and the red list covers less than 50 % of existing freshwater fish species (Sánchez-Zapata et al., 2016). For example, The IUCN acknowledged the construction of Stiegler's Gorge hydropower dam would negatively impact the ecology of the then Selous game reserve (now called Nyerere National Park) and life of organisms living outside this protected area (IUCN 2018). Despite the fact that the project will help to eliminate energy problems in Tanzania, its implementation is expected to provide negative ecological impacts, such as stopping the seasonal migration of fish (e.g. *Labeo cylindricus*, *Barbus macrolepis*, *Amphilius uranoscorpis*, *Chiloglanis deckenii*, and *Parakneria sp.*) from the Rufiji River to the Kilombero Valley Floodplains Ramsar site upstream for breeding (IUCN 2018); it may also lead to habitat destruction and siltation at the Rufiji-Mafia-Kilwa Marine Ramsar site through delta reduction and harm to marine species by sediment deposits and nutrients; starving of water to the largest mangrove forest in the Rufiji-Mafia-Kilwa Marine Ramsar site and fish, shrimp, and prawn fisheries (Kruitwagen et al., 2008); destruction of one of the most important habitats for wildlife and the heart of Nyerere National Park, where most of the animals roam, especially in the dry season (JFTULAS 2018).

### **Solar and wind- energy infrastructures**

Wind and solar energy developments has increased substantially all over the world, receiving support as alternative energy sources. In Tanzania, solar energy is used as a source of power by 24.7% of the households with access to electricity (Sarakikya et al. 2015). There is also an expansion of community interest in wind electricity generation prejudiced by factors such as an increase in oil costs, a long hydropower drought, and increased demand for power, which is influenced by high population growth (Bishoge et al. 2018). According to the World Bank (2019), Tanzania has a solar energy potential greater than that of Spain and wind energy potential greater than that of the US State of California. Based on the current research works, Tanzania has a lot of wind energy resources in the areas of Great Lakes, and the highland plateau regions of the Rift Valley (Bishoge et al. 2018). Wind farms with capacities of 100 MW in Singida will be constructed under the corporation with Six Telecom Companies in Singida, Tanzania; International Finance Corporation in Washington DC, The United States of America; and Aldwych International in London, the United Kingdom (Bishoge et al. 2018). Therefore, impact of solar and wind energy in Tanzania is an emerging conservation issue as there is direct impact on wildlife populations through habitat transformation and demographic unbalances as well as changes in ecosystem functioning at different scales (Kideghesho et al. 2013, Sánchez-Zapata 2016, Hamed & Alshare 2022).

Despite the absence of published and peer-reviewed information on the effects of solar energy on wildlife and their habitats in Tanzania, the occupation of the territory by solar and wind energy systems involves change in land use which results in ground-disturbing activities (Sánchez-Zapata 2016, Bishoge et al. 2018). Ground-disturbing activities affect a variety of processes including soil density, water infiltration rate, vulnerability to erosion, secondary plant succession, invasion by exotic plant species, and stability of cryptobiotic soil crusts (All of these processes have the ability—individually and collectively—to alter habitat quality, often to the detriment of wildlife. Any disturbance and alteration to the landscape, including the construction and decommissioning of utility-scale solar and wind energy facilities, has the potential to increase soil erosion. Erosion can physically and physiologically affect plant species and can thus adversely influence primary production (Jeffery & Joshua 2011, Bennun et al. 2021) and food availability for wildlife.

The development of solar and wind energy infrastructure has the potential to disrupt ecosystem balance, hinder wildlife migration, and interfere with gene flow between various species (Niebuhr et al., 2022; Sánchez-Zapata et al., 2016). Terrestrial species are generally affected by changes in the structure and function of their habitat, and these changes may be both from solar power plants and wind farms (Bennun et al. 2021). These renewable energy infrastructures may lead to fragmentation and the loss of animal species. Animals that fly, like insects, birds, and bats, are particularly vulnerable to wind turbines because they may crash into the rotating blades (Benítez-López et al. 2010, Niebuhr et al. 2022). For other taxa and large animals (e.g., zebra, wildebeest, impala, etc.), this infrastructure could cause animal avoidance over long distances and impair gene flow within populations (Niebuhr et al. 2022). This is particularly the case for tropical and subtropical countries like Tanzania, where the abundance of wildlife is high and wind power is expanding rapidly (Kideghesho 2013).

Moreover, wildlife behaviour and mating habits are also affected by the noise and visual disruption caused by solar and wind energy infrastructure (Hamed & Alshare, 2022; Niebuhr et al., 2022). Some adapt to these disturbances, while others abandon their home range in search of one that is quieter (Hamed & Alshare, 2022). The increased amounts of greenhouse gases and nitrogen oxides produced by solar plants could promote the spread of alien plants that suppress native species and raise the frequency of fires (Hamed & Alshare, 2022). Furthermore, the chemicals employed in these power plants for maintenance could have a negative long-term impact on biodiversity, such as causing the loss of native species (Hamed & Alshare, 2022).

### **Power lines and wildlife**

Energy produced by wind, solar and hydroelectric facilities not only impacts biodiversity during the production stage; these facilities also need power lines to transport the electricity to final consumers. An extraordinarily dense network of power poles and lines is located around cities and industrial areas, and have impacts on wildlife in various landscapes around the world (Kideghesho et al. 2013, Sánchez-Zapata 2016, Al-Razi et al. 2019, Hamed & Alshare 2022). Power lines have significant potential impacts on biodiversity, mainly through changes in habitat structure and wildlife mortality (Sánchez-Zapata et al. 2016).

With rapid development in many developing countries, mortality due to electrocution from power lines is among the major direct human causes of mortality of terrestrial animals worldwide (Al-Razi et al. 2019). The presence of poles and wires introduces lineal anthropogenic structures that alter the visual natural quality and create division lines on the landscape (Kideghesho et al. 2013). This applies especially to transmission lines, the higher voltage power lines (> 66 kV). Their presence causes severe changes in habitat structure, increasing fragmentation because of the removal of natural vegetation below the lines (Sánchez-Zapata 2016). Transmission power lines can behave as barriers to animal movements by disrupting migratory routes and promoting the development of avoidance strategies, as described for various wildlife animal species (Laurance et al. 2014, Hopcraft et al. 2015, Hopcraft et al. 2015, Torres et al. 2016, Sharma et al. 2018, Helldin 2019). Moreover, as a consequence of electric transmission, power lines generate strong electromagnetic fields, UV discharges and acoustic pollution which can affect animal health and behaviour and have also been identified as causes of wildfires (Kideghesho et al. 2013, Sánchez-Zapata 2016, Al-Razi et al. 2019, Hamed and Alshare 2022).

Probably the most serious environmental impact of power lines is avian mortality caused by electrocution, entanglement, and collision (Trombulak & Frissell 2000, Torres et al. 2016, Sharma et al. 2018). Mortality associated with power lines can accelerate the decline of several species and affect occupation patterns or population dynamics. For instance, the mega hydropower project construction is going on in Nyerere National Park. Thus, we argue that these infrastructures should be implemented outside and away from biodiversity-rich areas and/ or threatened or endangered species or ecosystems.

### **Pipelines and wildlife**

The East African Crude Oil Pipeline Project (EACOP) is a pipeline that will transport oil produced from Uganda's Lake Albert oilfields to the port of Tanga in Tanzania, where the oil will then be sold onwards to world markets (Andrew 2021). The oil projects pose immense environmental risks

and impacts, including both direct impacts to biodiversity resulting from the project placement and design, as well as 19 design and location of the Tilenga, Kingfisher and EACOP projects meaning that they will have extensive and adverse impacts upon critical habitats and natural ecosystems (Rosen 2022). The projects entail drilling over 130 oil wells (corresponding to 10 well pads) into Uganda's largest national park and constructing the world's longest heated crude oil pipeline through numerous protected ecosystems critical to the preservation of endangered species (Andrew 2021). In the opinion of experts and local communities, the significant biodiversity risks are so inherent to the project designs that they are impossible to adequately mitigate (Andrew 2021, Rosen 2022). Once built, the pipeline is expected to pose irreversible damage to biodiversity, natural habitats (forests, wetlands, and national parks), and water sources, as well as environmental and social risks to wildlife throughout Uganda and Tanzania (Andrew 2021, Rosen 2022). The installation of the pipe will require the removal of vegetation and the cutting down of trees, which puts terrestrial wildlife—both plants and animals—especially invertebrates and slow-moving vertebrates—at serious risk of perishing (Rosen 2023). The 400 kilometres of pipeline that will be laid across the Lake Victoria basin pose a significant risk of freshwater pollution and degradation, which increase the risk of health risks to aquatic species (Mugonza 2021).

The construction of the Tanzania-Zambia Railway (TAZARA) in the 1970s caused the degradation and loss of some plant and animal species in the Selous Game Reserve (SGR) and Magombera Forest Reserve (MFR) (Maganga 1994). This is also expected to happen for the ongoing SGR project. The MFR had 15 km<sup>2</sup>; however, about 50% of its area was reduced by ILLOVO sugar cane Company, thus lowering its conservation effectiveness (Marshall 2005). Given its ecological importance as the critical habitat for an endangered sub-species of red colobus monkey (*Colobus badius gordonorum*), reptiles and amphibians (Menegon et al. 2009), the MFR had to be annexed to SGR as a measure for improving its conservation effectiveness (Kideghesho et al. 2013).

### **Impact of Agricultural Development Infrastructure**

Food scarcity coupled with ecological deterioration due to climate change, land use change, and pollution is putting immense pressure on the global agricultural sector (Kideghesho 2013). To meet the global food demand, more uncultivated land is being developed for food production (Mbagalawe & Folmer 2000). Tanzania has carried out a large expansion and intensification of agriculture under the Kilimo kwanza (Agriculture First) initiative which has triggered the need for better knowledge on land use change effects and associated ecosystem functioning agricultural expansion is the main driver of deforestation. Deforestation contributes to many ecological crises, including the loss of biodiversity, carbon sinks, and useful resources (World Bank 2019).

Deforestation caused by human activities such as agricultural expansion within the buffer areas undermines the ecosystem and climate benefits of protected areas. Deforestation in buffer areas further undermines connectivity among PAs, and thus leads to isolation (Gizachew et al. 2020), which in turn can potentially cause restriction of the ability of plant and animal species to relocate to new geographic areas as well as changing plant community structure and diversity within protected areas because of herbivore concentration (Gizachew et al. 2020).

For example, in East Africa, the white-bearded wildebeest, found across Kenya and Tanzania is facing large declines due to incompatible land uses in their migratory corridors and dispersal areas (Kideghesho et al. 2013, Msoffe et al. 2011, Kideghesho et al. 2006). This has occurred as their migratory corridors and dispersal areas have become blocked or lost, limiting their migratory movements (Kideghesho et al. 2013, 2006). In Tanzania, in the Tarangire-Simanjoro ecosystem, the wildebeest migration from Tarangire National Park to the Simanjoro Plains declined by 88%, from 43,000 in 1988 to 5,000 in 2001 due to expanding cultivation and settlements blocking their migratory corridors (Bolger et al. 2008, Msoffe et al. 2011). Serengeti is a multi-ethnic region comprised of over 20 tribes (Emerton & Mfunda 1999) earning their living through crop production, livestock husbandry, charcoal burning, hunting and mining. These activities, taking place both within and outside the PAs, have detrimental impacts on wildlife habitats (e.g., destroy and reduce the range of space available for forage and breeding) and, consequently, wildlife populations. There is considerable human encroachment for agriculture in SNP and Maswa GR. Mining and settlements are increasing on the migratory corridors and dispersal areas along the western boundary of the SNP (Kideghesho et al. 2005).

### **The integrity of the United Nations Sustainable Development Goals in terms of wildlife conservation**

Many of the emerging infrastructure (i.e., expansion of roads, railways, dams' construction, human settlements, etc.) projects that aim to foster economic prosperity and alleviate poverty (e.g., SDG1: "No Poverty" and SDG2: "Zero Hunger") are mostly occurring in developing nations with high levels of biodiversity. However, these infrastructures have often not achieved these aims (i.e., improving the economy and alleviating poverty) because they are threatening or causing the loss of biodiversity (Caro, 2015; Caro et al., 2014; Hopcraft et al., 2015). The majority of these infrastructures undermine SDG 15's goal of promoting "life on land" as well as the Convention on Biological Diversity's overarching objective of "enhancing conservation of biological diversity" because they hurt the survival of wildlife species, habitats, and local communities' livelihoods (Caro et al., 2014; Hopcraft et al., 2015). Thus, for these infrastructure projects to support biodiversity conservation, their implementation should not jeopardize wildlife species and their ecological

habitats, as well as ecosystem services (Sharma et al., 2018; Torres et al., 2016). However, in order to reduce poverty and/or end hunger (SDG1: “No Poverty” and SDG2: “Zero Hunger”), for instance, in Tanzania, we need to increase food production. This may have a negative impact on biodiversity as most investors and local farmers will need to clear large portions of land, including natural forests, to expand agricultural fields. This could further involve putting in engineering infrastructure for irrigation and roads, as well as applications of synthetic pesticides and herbicides that may kill wildlife species, e.g. pollinators and other vital micro and macro invertebrates. Engineering projects that intend to divert water from rivers and streams either for irrigation or filling in the dams would have further large-scale impacts on wildlife species because they can decrease the depth of the river basin, thereby leaving it vulnerable to drought in times of low rainfall. Similarly, the ecological integrity of the rivers, streams, and wetlands may be destroyed, threatening already vulnerable or endangered species. Correspondingly, communities that depend on the river basin may face consequences that include their displacement. Thus, to ensure SGDs’ projects are sustainable, all planned or already implemented infrastructure development in Tanzania must be well-premeditated so that they do not jeopardize wildlife species and their habitats.

### **Concluding remark and way forward**

The review provides a thorough synthesis of the current understanding of how emerging infrastructures affect biodiversity. It offers direction, understanding, and a great chance for communities, decision-makers, developers, and academics to implement environmentally friendly infrastructures that promote the long-term conservation of wildlife. It calls for strategic land use planning to minimize the negative impact of infrastructure development and enable economic and social development. The review also advises the importance of involving conservationists in such planning to avoid unnecessary killing and/or displacement of wildlife species and degradation of habitats. Furthermore, it recommends that the development of infrastructures be designed in such a way that it ensures ecosystem health and safeguards environmental sustainability. In Africa, for example, energy demand is high and is anticipated to double or triple by 2030. Global hydropower capacity has been expanding for several years, resulting in thousands of new hydropower dams that are likely to result in habitat fragmentation and loss across Africa and cause long-term consequences for river health and protected areas. Lastly, the review recommends that African nations leave the traditional grid-based energy infrastructure and move towards solar and wind energy as part of efforts to protect critical habitats and wildlife and promote sustainable development.



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