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Mitigating the Effects of Infrastructure Development on the Environment

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Abstract
Infrastructure is closely linked to socio-economic development and research based on historical data has shown a significant positive association between economic growth and infrastructure in the long run. Infrastructure developments come with a range of social and economic benefits, however, it is not a panacea without side effects, having a range of negative effects on the environment owing to the fact that it is embedded in the natural system. Using the deductive approach to qualitative analysis, an extensive review of the literature was conducted. The research determines several factors that can be considered in mitigating the adverse effects of infrastructure development on the environment such as the use of green building and low-carbon infrastructure, sustainable building practices, renewable energy, waste management during construction and environmental legislation. Decision-making should therefore be guided by these factors established and incorporated into public policies necessary to promote sustainable economic development and environmental protection.
Keywords: Green Building; Infrastructure; Mitigation; Environment; Sustainable Economic Development.

1. Introduction

Infrastructure development, as defined by Osei et al. (2017), is the improvement of the quality of several components of infrastructure. It is a prerequisite for the development of any economy and thus plays an important role in stimulating economic growth, which in turn contributes to the reduction of economic inequality, poverty and other deficiencies in a country (Srinivasu & Rao, 2013). According to Snieška & Šimkūnaitė (2009), infrastructure may be regarded as *economic* and *social* infrastructure. Economic infrastructure is infrastructure that promotes economic activity such as road networks, airports, sea ports and telecommunication systems. Social infrastructure, on the other hand, is the infrastructure that has both a direct and indirect impact on the well-being of the members of society. This includes schools, hospitals, libraries and housing.
The significance of the natural environment goes beyond its role in addressing climate change; it also plays a vital role in human health. Plants and animals found in the natural environment provide the basis for many medicinal treatments for various illnesses, highlighting the importance of protecting the natural environment as a means of saving lives (Hashim & Denan, 2015; Pure Leisure, 2019). Furthermore, Asher et al. (2020) have emphasized that efforts to restore and safeguard the environment can contribute to approximately one-sixth of the necessary mitigation measures to combat climate change. However, studies have acknowledged that human activities such as agriculture, excavations, and infrastructure development can disrupt the environment (Haddaway et al., 2019). Infrastructure, in particular, contributes to anthropogenic greenhouse emissions throughout its entire socio-metabolic system (Gang et al., 2013). The construction of roads, for instance, leads to deforestation, while the production of cement, a key component of global infrastructure, is responsible for approximately 5% of global anthropogenic carbon dioxide emissions (Doyle & Havlick, 2009). These environmental impacts extend beyond emissions, as the effects of infrastructure built with concrete are also substantial but often overlooked. Infrastructure projects can offer tangible benefits, but they can also have significant environmental consequences, influenced by the interactions between the infrastructure and its surrounding environment (Teo et al., 2019). Furthermore, the Working Group on Environmental Auditing (WGEA, 2013) argues that although infrastructure has a long lifespan, it is not permanent. Infrastructure that has been in existence for more than fifty years is likely approaching the end of its design life and will require upgrades or decommissioning. It is during the construction, operation, and decommissioning phases that the effects of infrastructure become evident.

1.1. Ecology

Infrastructure which is viewed as necessary for development, particularly in rapidly growing populations may often have detrimental impacts on ecosystems. As highlighted by Torres et al. (2016), the primary causes of wildlife population decline and extinction in terrestrial ecosystems are habitat loss and degradation resulting from infrastructure developments and human settlements. Transport infrastructure, for example, is closely linked to habitat loss. WWF (2021) indicates that roads cutting through forests can fragment habitats and disrupt migration routes for endangered species. Moreover, roads not only facilitate the movement of goods and people but also provide access for hunters, posing a threat to wildlife. Another example is the environmental damage caused by oil spills from oil platforms, resulting in the death of aquatic species and contamination of shorelines. Consequently, infrastructure developments modify ecological conditions, disrupt highly suitable habitats, and contribute to the decline of wildlife populations (Seiler, 2015). The paving of roads through forests or the creation of lakes through dam construction instantly diminishes valuable habitats for plants and animals (WWF, 2021). Infrastructure, such as roads, can have detrimental effects on biodiversity by increasing mortality rates due to collisions, fragmenting and degrading habitats, and impeding the free movement and migration of wildlife (Anttonen et al., 2011; Karlson et al., 2014). These impacts can lead to long-term consequences, including the disruption of ecological balance through the introduction of invasive species by foot and vehicular traffic, evolutionary changes in wildlife, and the loss of ecosystems (Mandle et al., 2016). The utilization of land for infrastructure projects can hinder the movement of animals and affect population species, as habitats are destroyed. The construction of infrastructure brings about changes in land use, which can lead to damage and loss of habitat for the residing species. Consequently, this diminishes the capacity of the natural environment, species, and their habitats to adapt to climate change (Asmus et al., 2019; Li et al., 2020; Underwood et al., 2019). It is important to recognize that infrastructure developments not only impact the local ecology but also have potential effects on the surrounding areas. This can occur when species from the construction site are displaced and migrate to the surrounding regions, reducing the capacity of these areas to accommodate additional species and support the existing ones. Moreover, the ecological quality of these surrounding areas may decline, particularly when infrastructure development sites are in close proximity to nature conservation sites (Asher et al., 2020; Ghent, 2018).

1.2. Water

Water resources infrastructure plays a crucial role in the provision of sustainable water services for human livelihood in urban and rural areas, as well as supporting various industrial processes such as mining, construction, manufacturing, and agriculture. This infrastructure encompasses a wide range of components, including hydrological and meteorological stations, irrigation systems, underground and surface water storage facilities, and eco-tourism water infrastructure (Tumbare, 2015). In today's modern world, significant infrastructure projects have led to the diversion of water from water bodies such as rivers and lakes to meet the supply needs of cities and irrigate farms for agricultural activities. However, even the smallest diversions can render water bodies susceptible to drought during periods of low rainfall, compromising their stability and availability (WWF, 2021). Additionally, Akhmetshin & Kovalenko (2019) note that water infrastructure, such as dams that constitute over 60% of the world's rivers, can disrupt natural flow patterns and sediment movements, resulting in an increased risk of flooding and degradation of water quality. Similarly, large-scale infrastructure projects associated with the exploitation of natural resources, such as hydroelectric dams, can disrupt the biological and hydrological characteristics of free-flowing rivers, impacting migratory fish, reproductive habitats, fisheries, aquatic biodiversity, and riverine communities (WWF, 2006). Infrastructure construction and usage typically require a significant amount of water, which can create additional pressure on local water utility companies that may already struggle to meet existing demands. This increased demand for water from infrastructure developments becomes a serious concern, particularly in light of the growing challenges posed by climate change, which affect the quantity and quality of available water resources (Bray, 2019). Moreover, infrastructure projects themselves can be susceptible to flooding or pose a risk of flooding to the surrounding areas (Gunnell et al., 2019; Pregnolato et al., 2017). The operation of water utility infrastructure over time can lead to wear and tear, especially if proper maintenance is neglected. This can result in the failure of water supply pipes, leading to disruptions in water provision and the wastage of this valuable resource (Ortega-Ballesteros et al., 2021). Additionally, the construction, operation, and decommissioning phases of infrastructure projects can introduce contamination risks (Invernizzi et al., 2020).

1.3. Human Environment

Infrastructure plays a vital role in the pursuit and sustenance of high levels of human development. Essential components of infrastructure, including telecommunication, electricity, schools, water supply, and healthcare facilities, are closely intertwined with the attainment of human development (Mohanty et al., 2016). For instance, road infrastructure can enhance access to better healthcare services, schools, and employment opportunities, and attract private sector investments, particularly benefiting residents in rural areas (Hettige, 2006). However, it is important to acknowledge that certain infrastructure developments can have negative implications for the human environment. Displacement of communities occupying proposed construction sites and the consequent exposure of remote areas to communicable diseases are among the adverse effects of infrastructure projects (Zhang, 2011). Dam construction, which aims to provide electricity and water utilization, often leads to the resettlement of affected

residents (Fujikura, 2021). Furthermore, the construction of new roads and other infrastructure in areas with limited land zoning laws and regulations exacerbates impacts. These roads can facilitate criminal activities such as illegal mining, defrauding the government of revenue, illicit drug production, and theft of natural resources like timber, contributing to increased crime rates and moral decay in society (Asner et al., 2013; McSweeney et al., 2014).
The construction and implementation of infrastructure projects may result in the displacement of the local community, thus posing a threat to the sustainability of the culture and structure of the communities. This displacement may occur in surrounding areas or have a broader impact. For instance, the construction of a dam can lead to a reduction in water flow downstream, directly affecting the livelihoods of communities relying on it. Additionally, the local community may experience property loss due to demolitions required for infrastructure development, such as road construction (Hagen & Minter, 2020; Parraguez-Vergara et al., 2016). Moreover, infrastructure projects can present significant health risks to the local community. Examples include seepage of radioactive waste from nuclear plants, pollution of surface water from sewage or wastewater treatment plants, and exposure to electromagnetic radiation emitted by telecommunication towers (Krausmann et al., 2019). Furthermore, the construction of infrastructure can have implications for the preservation of archaeology, heritage sites, and other locations with architectural or historical significance (Gadzala, 2014).

1.4. Construction Materials

Besides unstable human activities resulting in serious environmental damage, the construction industry plays a major role in contributing to environmental problems owing to the large volumes of construction materials used. These materials, characterized by high embodied energy, result in substantial carbon dioxide (CO_2) emissions (Pektar, 2014). The global building and construction sector consumes large quantities of raw materials annually, with concrete and steel being the primary materials used, both of which have high embodied energy. The energy required in the production of cement, for instance, involves the combustion of fossil fuels, leading to CO_2 emissions (Eales & Clifford, 2013). Furthermore, Pektar (2014) asserts that the production and transportation of cement account for the largest proportion of CO_2 emissions. The environmental impacts associated with construction materials are generated at various stages in the life cycle of infrastructure, that is: during the manufacture of materials, during construction of infrastructure, use and operation of infrastructure, and ultimately during their disposal or demolition (Almusaed et al., 2020). Apart from embodied energy and the construction process, the operation of buildings has a significant environmental effect, primarily driven by energy consumption (Haddaway et al., 2019).
The majority of the materials used in the construction and operation of infrastructure are often obtained from sources that are not sustainable, thus causing harm to the environment during their extraction. These include materials such as timber which is obtained in a non-sustainable manner and consequently contributes to deforestation (Adhikari & Ozarska, 2018). Materials such as cement, which is a key component in the production of concrete, require a substantial amount of energy for its production processes. These processes contribute to approximately 5-7% of global carbon dioxide emissions, while steel production accounts for approximately 4-5% (Ashrafi et al., 2021; Izumi et al., 2021; Latawiec et al., 2018). Furthermore, the disposal of materials used for the construction of infrastructure can create large and complicated streams of waste, some of which can be hazardous (Luangcharoenrat et al., 2019). During the construction process, some materials such as timber require treatment before being used. The chemicals used in the treatment process can emit toxic substances such as polycyclic hydrocarbon potentially polluting the air and posing health risks. These pollutants may also become embedded within the final infrastructure (Låg et al., 2020).

1.5. Emissions into the Air

Since the onset of the industrial era and the widespread utilization of fossil fuels as an energy source, there has been a notable increase in the release of carbon dioxide caused by human activities (Dale, 1997). Infrastructure projects, throughout their entire life cycle, contribute to anthropogenic greenhouse gas emissions (Amen, 2021; Amen et al., 2023). These emissions occur during the construction phase, encompassing material production, manufacturing, and construction processes. They continue while the infrastructure is in use and persist during the final stage of its life cycle (Müller et al., 2013). In many cases, the construction and operation of infrastructure rely on fossil fuels rather than renewable energy sources (Gielen et al., 2019). This reliance on fossil fuels leads to the emission of greenhouse gases and other air pollutants. The emissions include carbon dioxide, carbon monoxide, dust, and nitrous oxides. These emissions not only contribute to climate change but also impact air quality and subsequently human health (EESI, 2021). Additionally, loss of energy along the transmission path of energy infrastructure such as electricity supply systems can result in emissions into the air (Owusu & Asumadu-Sarkodie, 2016).
The subsequent sections of this research paper are structured into three main parts. Section 2 provides an overview of the materials and methods employed in the study where secondary data was collected to address knowledge gaps through an extensive review of existing literature and analysed by content analysis approach. In Section 3, the focus

shifts to presenting the results and initiating a discussion that explores various mitigation measures for addressing the environmental impacts of infrastructure. These measures encompass green infrastructure, green building and sustainable construction practices, renewable energy and low carbon infrastructure, waste management during the construction phase and the role of environmental legislation. Finally, the last section of the paper offers a concise conclusion that summarizes the key findings and significance of the study, along with providing recommendations for future research endeavours.

2. Materials and Methods

In this study, secondary data was collected to address knowledge gaps. The collection of secondary data primarily involved an extensive review of existing literature in the field and the data collected was then analyzed using a deductive approach to qualitative analysis. This structured approach, known as content analysis, involved the creation of categories that represented key themes relevant to the research. The data was then systematically organized into these categories, allowing for a comprehensive analysis of the information obtained from the literature search.

3. Results and Discussion

Mitigation measures are often put in place to avoid, eliminate, reduce, regulate or compensate for the adverse effects of infrastructure on the environment, aiming to improve affected systems (Jain & Domen, 2016). These measures must be carefully considered before the implementation of infrastructure development activities and should be clearly outlined in both social and environmental impact assessments (Haddaway et al., 2019). While it may not always be possible to completely avoid the adverse effects of infrastructure developments on the environment, efforts should be made to minimize these effects to an acceptable level (Laurance et al., 2015). Evaluating the placement of infrastructure within the landscape is a key factor in achieving environmental success (Carvalho, 2017). In cases where a project cannot be avoided, it is essential to find a path that is economically, socially, and environmentally responsible (Ghent, 2018). Potential mitigation measures can include the careful selection of project sites and routes, integrating green practices into the construction process, engaging affected communities through consultative public hearings before project implementation, implementing planning controls and environmental legislation, and exploring alternatives to proposed projects (Smith, 2011; Zhang, 2011).
This section, therefore, explores various sustainable practices that can be employed to mitigate the environmental effects of infrastructure developments.

3.1. Green Infrastructure

In recent years, there has been growing emphasis on the concept of Green Infrastructure (GI) as a means of promoting sustainable land use. GI refers to intentionally designed natural or semi-natural spaces that serve various purposes such as providing new habitats for diverse species, mitigating high temperatures, managing floods, ensuring clean air and water, and reducing the negative impacts of urban development (Capotorti et al., 2016). GI has proven effective in managing rainfall discharge and non-pollutant sources associated with urban development and the increased use of impermeable surfaces (Kim et al., 2019). Urban areas often incorporate various components of GI, including public parks, green spaces, green parking lots, rain gardens, and green roofs, among others. These elements are implemented to counteract habitat loss, mitigate urban heat island (UHI) effects, and support biodiversity and species movement within urban environments (Kasada et al., 2017).

3.2. Green Buildings and Sustainable Building Practices

In modern cities, buildings have emerged as the largest consumers of energy, accounting for approximately 30-40% of total energy consumption. The construction industry alone is acknowledged as one of the largest contributors to global warming and environmental degradation, responsible for up to 33% of global carbon dioxide emissions. Energy usage in buildings typically includes heating, cooling, lighting, and powering appliances. Therefore, the construction and property sector presents vast opportunities for reducing energy consumption through the use of sustainable practices (Nurick et al., 2015; Pandey, 2015). Sustainability extends beyond mere activities that achieve eco-friendliness; it is a holistic approach aimed at addressing the negative environmental impacts of human activities (Marques & Loureiro, 2014). State-of-the-art buildings make use of materials that have low embodied energy and insulation values, such as clay, timber, straw, and recycled plastic, which can often be sourced locally, thereby reducing the high energy-intensive transportation costs. Furthermore, improved designs can minimize the reliance on conventional materials like steel and concrete (Aigbavboa et al., 2017). Integrating water-saving techniques into the design of a building can contribute to the conservation of this precious resource. Techniques such as rainwater harvesting, the use of greywater systems and garden butts can minimize water consumption in buildings. Rainwater can be harvested from underground tanks for later use, similarly, grey water from sinks and baths can be stored and reused for flushing toilets and watering gardens (Assayed & Hazaymeh, 2018; Khatakho & Koju, 2017).

3.3. Renewable Energy and Low Carbon Infrastructure

Buildings hold significant potential for achieving energy efficiency. The operational phase of a building's life cycle accounts for the highest energy consumption, primarily due to its prolonged duration and the energy required to maintain a comfortable indoor environment for occupants. During this phase, it is crucial to prioritize renewable energy sources and energy-efficient products to minimize energy consumption (Yüksek & Karadayi, 2017). Renewable energy sources, such as bioenergy, hydropower, geothermal energy, solar energy, wind energy and ocean (tide and wave) energy, replenish naturally without depletion and offer sustainable alternatives to fossil fuels (Owusu & Asumadu-Sarkodie, 2016). Low-carbon infrastructure, characterized by significantly reduced carbon emissions compared to conventional infrastructure, plays a vital role in enhancing resilience to climate change impacts. Examples include urban transport infrastructure, such as metros, which reduce reliance on cars - a major source of carbon emissions—and the utilization of renewable energy sources like solar power that emit less carbon than fossil fuels (Saha, 2018). Therefore, shifting towards renewable energy is a crucial step in environmental preservation and climate change mitigation (Wilkins, 2017).

Energy consumption in buildings is influenced by factors such as weather conditions and thermal comfort. For instance, more energy is consumed during colder periods than during warmer periods. Hence, proper building orientation can optimize thermal performance by allowing the required winter sun to enter the building and facilitating natural ventilation during summer, leading to potential energy savings of up to 35% (Albatayneh et al., 2018). The choice of building envelope colour also affects thermal performance, as lighter colours on surfaces can significantly reduce maximum indoor temperatures (Cheng et al., 2005). During the early stages of the design process, deliberate decisions must be made in relation to size, orientation and distribution of glazing to save energy and enhance the internal environment of a building. Passive cooling by natural ventilation is one of the methods that can potentially achieve thermal comfort (Sawachi et al., 2016; Taleb, 2014). In addition, shading techniques have a substantial impact on the overall thermal performance of buildings, improving comfort and significantly reducing energy consumption and related energy bills (Albatayneh et al., 2018).

3.4. Waste Management During Construction

The most effective approach to waste management is to focus on reducing the initial generation of waste, a step that is often overlooked (Narcis et al., 2019). As the availability of raw materials used in construction decreases, their extraction becomes more costly and environmentally detrimental. In addition, the use of landfills for construction waste disposal has adverse impacts on both humans and the environment. In light of these circumstances, recycling materials emerges as a more viable option for managing construction waste as opposed to disposal (Luangcharoenrat et al., 2019; Winkler, 2010). Therefore, recycling, in this scenario, entails returning materials that are no longer in use back into the production cycle, to conserve energy and natural resources (Marques & Loureiro, 2014).

3.5. Environmental Legislation

In recent years, numerous countries have made efforts to establish comprehensive and up-to-date environmental assessment frameworks. Nonetheless, for these legislative measures to be truly effective, regulatory authorities must possess sufficient authority, resources, and capabilities (Glasson & Therivel, 2019). The establishment of Environmental Impact Assessment (EIA) procedures has played a crucial role in identifying and evaluating the potential impacts and damages caused by various development projects on the environment and society. By doing so, these procedures help in anticipating and estimating the benefits, costs, losses, and consequences associated with such projects (Jain & Domen, 2016).

4. Conclusions

Infrastructure and socio-economic development are closely intertwined, as evidenced by research based on historical data, which demonstrates a significant long-term positive correlation between infrastructure and economic growth. Therefore, infrastructure development plays a crucial role in fostering social and economic progress. However, it is essential to recognize that such development is not without consequences, as it operates within the intricate framework of the natural system and should therefore be approached with careful consideration of its environmental impacts. The adverse effects associated with infrastructure development can be mitigated to pave the way for a more sustainable and resilient future through various measures discussed in this paper. One key approach is the implementation of green infrastructure, which involves designing and planning natural or semi-natural spaces to provide habitats for species, manage floods, reduce temperatures, and improve air and water quality. Additionally, adopting green buildings and sustainable practices can significantly reduce energy consumption, minimize environmental impacts, and promote resource efficiency. Embracing renewable energy sources and low-carbon infrastructure not only helps combat climate change but also contributes to building resilience in the face of environmental challenges. Efficient waste management during the construction phase and the enforcement of environmental legislation are equally vital. By reducing waste generation and promoting recycling, valuable resources can be conserved while minimizing the detrimental impact on the environment. Furthermore, robust environmental legislation and regulatory authorities with adequate power and resources are essential for ensuring effective implementation and enforcement. To safeguard the environment and promote sustainable development, deliberate infrastructure decisions must be integrated into public policies. These decisions should prioritize the factors highlighted in this research, considering the long-term environmental implications and seeking a balance between social and economic benefits. It is therefore essential for policymakers, various stakeholders, businesses, communities, individuals and society as a whole to collaborate in embracing these measures and integrating them into the collective vision for sustainable infrastructure development. By taking such actions, it becomes possible to strive towards sustainable infrastructure development that reduces environmental harm and promotes societal progress.

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Conflict of Interests
The authors declare no conflict of interest.

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