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The Need for Resilient Infrastructure as an Adaptive Measure for Climate Change

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ABSTRACT: *Climate change is one of the most pressing environmental issues of the 21st century, and its impacts extend to the current society's infrastructure. Consequently, the need for resilient infrastructure to withstand climate impacts becomes paramount. This paper reviewed the need for resilient infrastructure in today's society. Literature was reviewed under three major subcategories viz a viz impacts of climate change on infrastructure, impacts of infrastructural development on climate change, and climate-resilient infrastructure. It was found that the extent to which climate change translates into risks for infrastructure depends upon the interaction of the changing climate hazards with the infrastructure. In Nigeria and Africa at large, many infrastructures give an unsatisfactory performance, and they are short-lived due to technical and non-technical factors. Extreme weather events due to climate change will likely increase disruption to these infrastructures. The paper recommended a great need to overhaul already existing infrastructure to withstand climate change disruptions better.*

KEYWORDS: climate change; resilient infrastructure; sustainable infrastructure.

INTRODUCTION

Together with the decarbonization lifestyle, improving infrastructure's resilience to climate change impacts is a main agenda for maintaining economic and future growth (DEFRA, 2020). Climate change adaptation strives to decrease climate change risks and vulnerabilities while also increasing climate resilience. To withstand or adapt to the negative effects of climate change, one good approach is to invest in climate-resilient infrastructure.Climatic-resilient infrastructure, according to the OECD (2018), is planned, designed, built, and operated infrastructure in such a manner that it predicts, prepares for, and adapts to changing climate conditions. It can also endure, adapt to, and recover quickly from disturbances brought on by climate change. Climate resilience is a process that continues throughout an infrastructure's lifecycle. Climate resilience measures can be mutually reinforcing with attempts to build natural disaster resistant infrastructures.

Climate-resilient infrastructure minimizes the risk of climate-related disruptions, although it does not completely eliminate them. Increasing climatic hazards with exposure and sensitivity determines the extent to which climate change translates into infrastructure risks (Agard & Schipper, 2014). Climate risks to infrastructure can be mitigated by situating assets in less vulnerable regions (e.g., avoiding new construction in flood plains) and improving the assets' ability to cope with climate impacts when they occur (such as drainages that can handle increasing precipitations when they occur). Infrastructure development should also evaluate the effects of external risks, such as the possible contribution to flood risk from increased paved surfaces.

Background to the Study

The world we live in is a dynamic entity and as such, it is susceptible to changes. Climate change entails a change in climate patterns, either globally or regionally. An alteration in temperature and weather patterns resulting from nature and human activity, like burning fossil fuels, natural gas, oil, and coal which releases greenhouse gases into the atmosphere. This can also include long term changes on land surfaces, oceans, and ice sheets.

Natural variations in global climate occur on time spans ranging from decades to thousands of years and beyond. Internal fluctuations that exchange energy, water, and carbon between the atmosphere, seas, land, and ice, and external impacts on the climate system, such as changes in the energy received from the sun and the effects of volcanic eruptions, are two sources of natural variations. Human actions can also affect climate by altering CO2 and other greenhouse gas concentrations in the atmosphere like aerosol concentrations, and the reflectivity of the Earth's surface by change in land cover. (Australian Academy of Science, 2021).

As climate changes, the earth systems respond by a way of feedback. This could be injurious to infrastructure and lead to economic loss. Hence the need to produce resilient infrastructure. Resilience, with respect to infrastructure refers to the ability of such infrastructure to withstand changes in the climate pattern and still maintain their basic function and structural capacity. Thus, a resilient infrastructure is one that has the ability to withstand, adjust, adapt to changing conditions, and recover positively from shocks and stresses.

Infrastructure shapes the urban environment and drives long-term, equitable economic growth. It is our obligation to build high-quality, dependable, long-term, and resilient infrastructure that supports economic growth and social well-being (Council of Europe, congress of local and regional authorities, 2021). Climatic-resilient infrastructure is defined by the fact that it is planned, constructed, built, and managed in such a way that it predicts, prepares for, and adapts to changing climate conditions. It can also endure, adapt to, and recover quickly from disturbances brought on by climate change (OECD, 2018). Infrastructure that is climate-resilient has the potential to improve service dependability, extend asset life, and safeguard asset returns. The path forward is constructing robust infrastructure, fostering sustainable industrialization, and encouraging innovation.

After decades of underinvestment, Africa's progress is limited by a lack of infrastructure. The fulfillment of the Millennium Development Goals would be considerably aided by good infrastructure (MDGs). Climate change will put a strain on present infrastructure, worsening existing flaws and necessitating large-scale repair and replacement projects backed by finance and technology and carried out by qualified workers. Concerns about new weather and climate threats will have to be factored into infrastructure development. As proposed by the Climate for Development in Africa (ClimDevAfrica) initiative, capacity training and significantly improved climate information will be necessary, as will a wider interchange of best practices across Africa (UN. ECA African Development Forum, 2010).

Statement of the Problem

A community's infrastructure system is its lifeblood. Infrastructure that is of high quality not only beautifies the environment, but also improves people's quality of life. This includes not only the conveniences of heat in the winter, reading lights at night, and easy transportation options, but also items critical to public health and safety, such as water treated to human-safe standards, energy for critical operations, and transportation to enable society's daily functioning (Conner, 2011). Global climate change as a result of greenhouse gas emissions (GHGs) has a wide range of consequences and has the potential to be very significant, making it the most important long-term environmental concern now confronting the globe (Paul, Tom, and Ruth, 2005). Climate change poses a critical threat to future development, especially in developing countries and areas where poverty is predominant and key assets such as infrastructure currently in use are underdeveloped (Amy, Paul, Xavier, and Michael, 2014).

Infrastructure in developing countries like Nigeria and most African countries is short-lived because most of them are constructed with inferior materials and are subject to corruption. Some of these infrastructures were not designed with climate change in mind, and as a result, thier long-term viability is not guaranteed. Roads provide a lifeline for economic and agricultural livelihood in rural regions, particularly in low-income nations, as well as a variety of indirect advantages such as access to healthcare, education, credit, political involvement, and more (Amy *et al*, 2014). There have been cases of degradation here and there, series of erosions, flood, bridge failures, building collapse, road failures, and outbreak of diseases amongst others as a result as a result of extreme weather events caused by climate change. Extreme weather events births hazard to the available weak infrastructure in terms of degradation and the lifespan of said infrastructure.

There is no doubt that the climate is changing, evidence abound everywhere. There is ample evidence showing that climate fluctuations have often been involved in generating conflicts and perturbations in human history (Diamond, 2005; Buentgen,, Tegel, McCormick, and Trouet, 2011). Today, global warming is already causing an expansion of deserts and a rise of sea levels. Impacts on infrastructure, resulting from storms, earthquakes, floods, erosion, and landslides, are already causing considerable hazards to the weak infrastructures on ground. Impacts on infrastructure in turn affect energy and food supplies. However, in contrast to earlier climate fluctuations, the current climate change is unprecedented as its origin is clearly anthropogenic (IPCC, 2014). If infrastructures are not built with resilience in mind, we will end up bequeathing an unhealthy environment to the future generations as the continuous change in weather and climate patterns will lead to uninhabitable regions on a grand scale.

While the need for resilient infrastructure might seem obvious, especially in the face of erratic weather and climate, it is important to clearly point out the role of resilient infrastructure in climate change adaptation.

Aim and Objectives

The aim of this paper is to investigate through literature review the need for resilient infrastructure as an adaptive measure to climate change.

To achieve this aim, the following objectives were sought:

- To identify the impacts of climate change on infrastructure,
- To identify the impacts of infrastructural development on climate change,
- To review the need for resilient infrastructure in a changing climate, and
- To synthesize the literature so reviewed and make recommendations.

LITERATURE REVIEW

Review of relevant literature was under the following sub headings

- Impacts of climate change on infrastructure
- Impacts of infrastructural development on climate change
- Climate Resilient infrastructure

Impacts of climate change on infrastructure

Chinowsky, Schweikert, Strzepek, and Strzepek (2015), researched on infrastructure and climate change: a study of impacts and adaptations in Malawi, Mozambique, and Zambia. The study looked at the impact of climate change on Malawi's, Mozambique's, and Zambia's road infrastructure. The study used a stressor-response technique to calculate the impacts of expected precipitation, temperature, and flooding variations on these countries' paved and unpaved road infrastructure. The results of running 425 climate models for each road design and policy choice from 2010 to 2050 were discussed. According to the report, the three southern African countries might face a $596 million bill to maintain and repair roads as a consequence of damages directly attributable to temperature and precipitation variations as a result of climate change until 2050. The study concluded that the challenge for policy makers is to determine the potential risk that a country is facing based on the uncertainties associated with the multiple aspects of climate change modeling.

According to the study carried out by Purwanti and Nurmuntaha (2017), on Climate Change Risks to Infrastructures. Infrastructure is meant to be developed with a certain design lifecycle in mind, and it is assumed that the infrastructure would be functional and long-lasting during that time. Through research of relevant literatures, the report offered a general viewpoint of the influence of climate change on infrastructure in a regional system. Climate change, according to the report, may harm energy infrastructure, particularly in extraction, generation, and transmission, reducing efficiency and disrupting operations. Climate change is a fact, as evidenced by rising average sea levels, rising temperatures, and extreme weather events; it has a variety of repercussions on infrastructures, necessitating adaptation to mitigate the negative effects; and infrastructures are interconnected and interdependent. A damage of one infrastructure will affect the others. The study recommended that data is very essential for analysis and decision making, therefore the improvement of database is highly required.

Amy, *et al* (2014), did a work on Climate change and infrastructure impacts: comparing the impact on roads in ten countries through 2100. The study looked at the impact of 54 different AR4 Global Circulation Model (GCM) future climate change scenarios on current road networks in 10 geographically and economically varied nations. The research was carried out with the use of a software program that employs engineering and materials-based stressor-response functions to assess the influence of climate on maintenance, repair, and construction. The methodology and application of the IPSS tool to nations reflecting a variety of incomes, including low-income, middle-income, and upper-income countries, were the emphasis of the article. For each nation, the IPSS tool was used to compare adaption costs and opportunity costs. As early as 2025, nine out of ten nations in the research had implemented a proactive adaption strategy that resulted in lower fiscal costs and better connection rates. The findings revealed that higher-income nations incur large economic expenses as a result of extensive road networks, with particularly high costs in Japan and Italy. Adaptation has exceptionally high benefits in Bolivia, Ethiopia, and Cameroon, but the costs of merely maintaining current networks are similar to financing equal to doubling or tripling the present paved road inventory. Climate change has a high cost in terms of maintenance, repairs, and lost connection, according to the report, but many of these costs may be managed or prevented by using proactive adaption measures. These findings can aid policymakers at the national and international levels in determining where and how to invest, as well as demonstrating that climate change poses a serious and immediate danger to transportation across the world. The report suggested that important attention be given to safeguarding present and future infrastructure investments, as well as the economic, social, and other roles they serve.

Dmitry, Luis, Nikolay, Boris, and Dmitry (2019) conducted study on the effects of climate change on buildings, structures, and infrastructure in permafrost-affected Russian areas. The research looked at the extent to which permafrost affects infrastructure and housing in Russia, as well as the value of these assets. In order to assess the cost of buildings and infrastructure affected by permafrost degradation by the mid-twentieth century under the RCP 8.5 scenario, an ensemble of climatic forecasts was applied as a forcing to a permafrost-geotechnical model. The overall value of fixed assets on permafrost was assessed to be 248.6 billion dollars, according to the findings. Climate change is expected to harm 20% of structures and 19% of infrastructure assets, with mitigation costs of 16.7 billion dollars and 67.7 billion dollars, respectively. By the mid-twentieth century, the entire cost of residential real estate atop permafrost was projected to be $52.6 billion USD, with 54 percent of structures damaged by considerable permafrost deterioration. Changes in climatic circumstances are likely to raise permafrost temperature and the thickness of the active layer, according to the study which in turn, can destabilize geotechnical environment and affect buildings and structures on permafrost. These revisions are expected to effect 54 percent of all permafrost residential structures, valued a total of $20.7 billion USD. The study recommended that a long-term monitoring permafrost network be established at the federal and state levels in order to reduce the costs of permafrost changes, while local municipalities and industries on permafrost should include permafrost monitoring in their planning and operational activities.

Dellink, Hyunjeong, Elisa, and Jean (2017) investigated the effects of climate change on international commerce. The study looked at how climate change damages can influence international commerce in the next decades, as well as how international trade can assist reduce climate change costs. The direct consequences of climate change were shown using a qualitative analysis and a literature study. The OECD's ENV-Linkages model, a dynamic computable general equilibrium model with global coverage and sector-specific international trade flows, was used to examine the indirect effects of climate change damages on trade. The modeling research demonstrated a likely scenario of future socioeconomic developments and climatic damages, based on the analysis in the OECD (2015) publication "The Economic Consequences of Climate Change," to give insight on the mechanisms at work in explaining how climate change would affect commerce. Climate damages would put negative pressure on virtually all areas' economies through reduced trade flows, according to the results of the ENV Linkages model simulations, compared to a scenario that excludes climate change's economic feedbacks. The study found that changes in international commerce are influenced not just by domestic climate impacts, but also by the intensity of these impacts in comparison to significant trading partners.

Impacts of Infrastructural Development on Climate Change

Infrastructure that is well-designed may have a good influence on the environment, which is equally important for growth. However, infrastructure expenditures have a negative side: they frequently result in environmental deterioration. Emissions from fossil fuel energy generation and transportation lead to acid rain locally and worldwide warming. Flooding, water contamination, and community upheaval are among risks associated with hydropower and irrigation (world bank, 2007).

Ali and Mirza (2015) published a paper summarizing the impact of climate change on Canada's civil infrastructure and many related engineering, policy and funding considerations. After highlighting the various impacts, including increased temperatures and humidity levels, rising seawater levels, ice jams, increased precipitation and longer droughts, and their impact on infrastructure such as roads and housing, the study recommended that the Federal Government take the lead in bringing together all interested parties from the public and private sectors to review current and future infrastructure needs. This might include a long-term infrastructure policy as well as 10- to 15-year regional and local plans with guaranteed funding from a national infrastructure bank that is jointly funded and administered by the public and private sectors.

Depending on the steps taken, climate-resilient infrastructure can provide a variety of advantages over business as usual. Increased service delivery dependability is one of them. Ex-post, reliable infrastructure benefits by minimizing the frequency and severity of outages. Ex-ante, it provides advantages since it minimizes the need for customers to spend in backup procedures. Another benefit of climate change reliant infrastructure is that it prepares for climate change from the start, avoiding the need for costly retrofitting and reducing the chance of the asset becoming obsolete early. The magnitude of the advantages varies depending on the situation, however Hallegatte et al. (2013) predicted that spending USD 50 billion per year (annualized) on flood defenses for coastal communities would cut expected losses from USD 1 trillion to USD 60-63 billion in 2050. Projects may not always achieve all of their goals, and trade-offs between climate resilience and other policy goals will frequently be necessary.

Climate Resilient infrastructure

The objective of the 2015 Paris Agreement was to keep temperature rises "well below 2$^{\circ C}$ over pre-industrial levels" and to pursue efforts to keep them to 1.5°C above pre-industrial levels. If that aim is to be realized, current NDCs show that collective ambition must be strengthened (Vandyck, Keramidas, Saveyn, Kitous, & Vrontisi, 2016). Limiting temperature rises to well below 2 degrees Celsius would lower the danger of "severe, widespread, and permanent" changes, but people and ecosystems would still have to adjust to potentially substantial negative consequences (IPCC, 2014). Infrastructure should be compatible with low-GHG transitions while also being robust to climate change consequences. Because infrastructure assets have such a lengthy lifespan, actions made now will lock in vulnerability if they do not take these factors into account.

Building climate-resilient infrastructure has different problems in different countries. The main challenge in developing countries and emerging economies is to build new infrastructure to support the expansion of urban areas and the development of new cities, as well as to ensure that everyone has access to energy and safe drinking water, and to connect people through transportation and telecommunications. Countries are also faced with the task of constructing infrastructure to mitigate the danger of natural catastrophes such as floods. The difficulty of replacing and updating old infrastructure and networks is mostly faced by industrialized countries, especially when technology advancements and legislative decisions give chances to boost efficiency and reduce emissions. Extreme weather events starkly highlight how infrastructure services may be vulnerable to climate change's consequences. Flooding in eastern China in 2011 destroyed 28 train lines, 21,961 roads, and 49 airports, as well as knocking out electricity to millions of people (Xi, 2016). The water level in So Paulo's main reservoir plummeted to 4% of capacity in 2015, resulting in water restriction and societal unrest (Vigna, 2015). In the absence of response, climate change is expected to double the damage to infrastructure caused by extreme weather events in Europe by the end of the century (Forzieri, et al., 2018). Trend changes, in addition to extremes climatic events, will have a large effect on infrastructure. In the event of a dry environment, the value of hydropower output in Africa might fall by as much as USD 83 billion, resulting in increased consumer costs (Cervigni, Liden, Neumann, & Strzepek, 2016). The floods in Nigeria in August-October 2012 drove rivers over their banks and inundated hundreds of kilometers of urban and rural territory (Ojigi et al., 2013), affecting an estimated 7,705,378 Nigerians and displacing 2,157,419 people internally (IDPs). In addition, between July and October 2012, 363 people died and over 618,000 homes were destroyed in over 90 percent of the country's 36 states (UN-OCHA, 2012). Food insecurity was resulted in sections of the country (FEWS NET, 2012; FEWS NET, 2013), particularly Anambra and Imo States (FEWS NET, 2012; FEWS NET, 2013). Therefore, the need for climate resilient infrastructure cannot be understated if we hope to survive climate change.

Summary of the Literature Review
Climate change will expose the infrastructure systems to new risks while facing already numerous challenges. These challenges include ageing infrastructure, changing demand and supply (resource) conditions, limited R&D and innovation funding, new technologies rapidly becoming available, increased competition for both funding and use of priority public spaces, rising energy costs and an ever increasing need to address climate change. Chinwosky et. al 2015 established that three southern African countries are facing a potential $596 million tag after running 425 climate scenarios for each road type and policy option from 2010 to 2050. The study estimated that the three southern African countries are facing a potential $596 million price tag based on median climate scenarios to maintain and repair roads as a result of damages directly related to temperature and precipitation changes from potential climate change through 2050. This scenario will continue to reoccur if climate resilient infrastructures are not built. Amy, *et al* (2014) also established that climate change is affecting critical infrastructure.

Well-designed infrastructure can have positive impacts on the environment, which also is crucial for development. Climate-resilient infrastructure can yield a range of benefits depending on the measures that have been implemented. These include increased reliability of service provision and reduced cost of maintenance and lost time during maintenance or repair. The challenges of building climate-resilient infrastructure vary by country and mostly boil down to funds, but the risk of doing nothing has led to various disasters around the world because the existing infrastructure could not absorb the climate caused disaster. One notable example is the August-October 2012 floods in Nigeria that rendered over two million Nigerians internally displaced. At the end, it costs more to recover from climate disasters.

DISCUSSION

The extent to which climate change translates into risks for infrastructure depends upon the interaction of changing climate hazards with exposure (the location of assets) and vulnerability ("the propensity or predisposition to be adversely affected") (Agard & Schipper, 2014).

In Nigeria and Africa at large, many infrastructures give unsatisfactory performance and they are short lived due to several factors, both technical and non-technical factors. For instance, most of the drainage networks do not convey surface run-off because they are full of waste; some of them do not have the capacity to contain surface runoff that results from excessive rainfall that was not borne in mind while designing the drainages. Roads and highways which usually last a long time no longer last as long because of increased precipitation that create potholes and saturate the underlying soil.

Extreme weather events due to climate change will likely continue to disrupt infrastructures. When infrastructures performance in a region is disrupted, it will impact other sectors including economic and public health sectors (Puwanti *et al,* 2017) thus, making the need for better and resilient infrastructures needed. Literatures show that there's a relationship between climate change and infrastructure; unsustainable practices of infrastructural development can increase global warming; on the other hand, climate change brings disaster to infrastructure.

Built infrastructure is supposed to be planned with certain designs that can withstand change in climate, and also reduce production of greenhouse gases. Climate risks to infrastructure can be reduced by locating assets in areas that are less exposed to climate hazards (e.g., avoiding new construction in flood plains or areas prone to land slide), and by making the assets better able to cope with climate impacts when they materialize (OECD, 2018). For example, sea walls may need to be constructed to address the physical impacts of storm surges or rising see level as a result of climate change. The development of infrastructure should also consider the impacts on risk elsewhere: for example, increases in paved surfaces which contributes potentially to flooding.

The need to build climate resilient infrastructure cannot be over emphasized as this change in climate will continue. There is a great need for an overhauling of already existing infrastructure. They may need to be retrofitted, or managed differently, with respect to the changing climate. New infrastructure assets should be prioritized, planed, and designed with inbuilt resilience for climate changes that may occur throughout their lifecycle. They should be built in such a way that they have the ability to adapt to climate change with little or no emissions.

CONCLUSION AND RECOMMENDATION

Conclusion

Climate change is real, and it has already begun to affect us. The average sea level has risen, the average atmospheric temperature has risen, and extreme weather events have occurred. This transformation has a number of implications for infrastructure, necessitating the need to mitigate the negative consequences. In addition, infrastructures are interconnected and interdependent. Damage to one will cause damage to others, either directly or indirectly, because it is a system. The fulfillment of the sustainable development goals can be aided by ensuring infrastructure resilience to climate change. Climate-resilient infrastructure may also help to raise living standards and improve quality of life, as well as boost service dependability, extend asset life, and safeguard asset returns. All hands should be on deck in building climate resilient infrastructure.

Recommendation

Having established that resilient infrastructure is an adaptive measure for climate change, several actions are recommended to improve reliability on current and future infrastructure. Higher, stronger, and better engineered roads and bridges; efficient monitoring and communications technology; and the use of alternative energy sources to minimize greenhouse gas emissions are all things that need to be rebuilt and redesigned in response to the changing climate. For a long time to come, the enormity of the potential impacts of sea-level rise, storm effects, and heat — in tandem with continuous changes in the natural environment — will demand attention and investment (Wilbanks, and Fernandez, 2013).

To guarantee that new and current infrastructure networks are robust to climate change, a coordinated policy response is required. Massive worldwide action, continent by continent and country by country, is required to combat climate change. To combat climate change, we'll need more and better public transportation to get people out of their automobiles and encourage increased population density in cities to lower the distance people must drive to work. To increase the quality of urban life, additional urban infrastructure, such as municipal water, urban parks and leisure, and cultural centers, such as museums, will be required (Wikipedia). All these are infrastructures that need to be resilient in this time of climate change.

Area for Further Study

The role of resilient infrastructure as an adaptive measure for climate change has been established in this paper, but there is still need to narrow the scope down and study the role of each infrastructure such as roads, bridges, rail systems and building in adaptive climate change behavior.

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