Energy-Efficient Urban Landscapes: Advancing the Built Environment through Sustainable Ecological Planning

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Abstract- The growing urgency of addressing environmental challenges highlights the need for research on their impacts on the built environment, particularly in urban areas where these issues adversely affect residents' well-being. Despite increasing recognition of climate-related challenges, limited attention has been given to adaptive strategies that harness local ecological resources, such as indigenous flora and green infrastructure, to promote energy efficiency and sustainability. This study examines strategies to enhance Nigeria's urban landscapes through energy-efficient approaches in response to ongoing environmental changes. The objectives include: (i) identifying key factors influencing climate change and (ii) evaluating adaptive strategies for enhancing energy efficiency and resilience in urban environments. This research employs a total of 235 surveys amounting to 78.30 per cent of the sample that was gathered and examined. The Logistic regression analyses of Statistical Package for the Social Sciences (SPSS) software package Version 22 were used to analyze the collected data from online survey distributions. The results reveal that all factors related to climate change adaptation are statistically significant (p-values < 0.05), underscoring their critical role in fostering energy efficiency and resilience. The findings provide robust evidence for prioritizing national and regional adaptation strategies. Recommendations include integrating the significant factors into urban planning policies, emphasizing energy-efficient solutions, and fostering community engagement and education to promote awareness and adoption of adaptive measures. Future research should explore emerging technologies and interdisciplinary approaches to address energy efficiency, and climate risks, and offer a comprehensive framework for sustainable urban transformation.

Keywords Energy efficiency, Climate change adaptation, Sustainable urban planning, Ecological resources, Resilient urban ecosystems

1. Introduction

The impact of environmental change remains a vital issue confronting nations throughout the world today. Environmental change refers to significant alterations in long-term patterns and characteristics. These changes manifest through various empirical indicators, including shifts in average temperatures, and precipitation patterns in the distribution of climatic zones over extended periods. Unlike short-term fluctuations or natural variability, climate disruption denotes persistent and often unprecedented deviations from historical norms, driven primarily by human-induced factors such as carbon emissions, and alterations to land use [1],[2]. Consequently, these impacts result in heightened environmental heat, intensified winds, increased pollution, and habitat destruction, among other adverse outcomes [3]. In response to these challenges, numerous developing nations worldwide are actively working to combat the consequences of environmental change.

The development of an energy-efficient urban environment is crucial for the reduction of energy consumption, promotion of sustainability, and enhancement of urban resilience in the face of climatic challenges. Being great consumers of energy, urban areas, which account for more than 70% of global energy consumption, contribute much to greenhouse gas emissions and environmental degradation [4]. It has been identified as one of the major concerns of urban planners, policymakers, and researchers to apply strategies that can reduce energy consumption and carbon emissions in urban settings. A basic strategy for increasing energy efficiency in urban environments is through the use of green building practices. In a more specific sense, these buildings, featuring environmentally friendly building materials, optimization of energy consumption, and integration with renewable sources of energy, such as solar panels and wind turbines, could substantially lower the energy impact that characterizes urban environments [3-4]. The adoption of energy-saving technologies, such as LED lighting, smart HVAC, and automated energy management systems, enables urban environments to lower both operating expenses and their environmental impact [5]. Second, the technologies help in exercising better control over energy use and make buildings increasingly responsive to dynamic environmental conditions and user needs, features that are particularly valuable in cities facing increasingly uncertain climates.

Beyond the concept of green buildings, urban design contributes to creating environments that help to use energy efficiently. Several green spaces planned in cities, such as urban parks, green roofs, and tree canopies, could help moderate the effect of urban heat islands by reducing cooling energy needs while improving air quality. For instance, urban trees bring shade, reduce the need for air conditioning in nearby buildings, and assist natural ventilation, all of which lead to energy savings [4-5]. In addition, using green infrastructure in urban settings, such as permeable pavement and city wetlands, helps in managing stormwater and reduces the energy consumption associated with water treatment plants. The adoption of these sustainable practices helps to conserve biodiversity and increases the resilience of urban areas to climate change, including extreme weather events like floods and heatwaves. Nevertheless, urban resilience goes in tandem with energy efficiency, for cities that are well-prepared to lower energy consumption and cope with their resources efficiently are also well-ready to handle the effects of climate change.

Resilient urban environments combine the synergy of smart technologies, sustainable materials, and forward-thinking policies to address the challenges brought about by rising temperatures, flooding, and other climate-related stresses. For instance, climatically responsive architecture using passive design strategies, like natural shading, daylighting, and thermal insulation, can greatly lessen the requirement for mechanical heating and cooling systems, thus increasing the resilience of buildings resisting changing the climate [1-2]. In addition, urban public transport systems that major in energy-efficient and low-carbon options, such as electric buses and trains, can greatly reduce energy consumption within cities. Non-motorized transportation, like cycling and going on walks, encourages the reduction in the use of private vehicles and thus cuts down energy consumption and traffic congestion. Moreover, smart grids and energy storage systems can enable cities to optimize energy distribution, reduce energy waste, and integrate renewable energy sources, which enhance overall energy resilience.

There are strong signals that the effects of the changing climate in Africa are likely to continue unless important preventive steps are taken. This was a result of the fact that African cities are important producers of greenhouse gases; while environmental issues have equally increased due to the pollutants traceable to urbanization [6]. Despite these challenges, African nations lack sufficient financial and human capital needed to counteract the effects [2]. Nigeria's coastal areas are especially susceptible to the effects of environmental change because of the threat posed by rising sea levels and coastal erosion to nearby residences, commercial buildings, and vital infrastructure. For example, coastal flooding and erosion are already causing damage to property and infrastructure, displacing communities and disrupting economic activities. Furthermore, the energy consumption associated with heating, cooling, and powering buildings contributes to greenhouse gas emissions, exacerbating climate change. Thus, lowering the built environment's carbon footprint is crucial for lessening the effects of environmental degradation in Nigeria, where population increase and urbanization have pushed up energy demand.

The land usage dynamics in Nigeria exhibit a concerning trend, with a degradation rate of 4000 km2 per year, far outpacing the reforestation efforts which stand at a mere 10 km2 annually [7]. This imbalance has led to a decline in forested areas, with only 10.80% remaining as of 2008, indicating a significant loss of crucial ecosystems over the years. In terms of demographic shifts, the urban population has been experiencing rapid growth, with an annual increase of 3.80%. In 2004, urban dwellers comprised 45% of the total population, a figure that rose to 48.9% by 2010 [8]. This urbanization trend highlights the ongoing migration from rural to urban areas, reflecting changes in economic opportunities and lifestyle preferences. The Agenda 2030 Millennium Development Goals (MDGs) serve as a critical framework for addressing persistent environmental challenges. However, despite these global initiatives, effectively mitigating the impacts of urban pollutants, flooding, and other environmental issues remains a significant hurdle in achieving environmental sustainability and the Sustainable Development Goals (SDGs) [9]. Integrating environmental considerations into urban planning, infrastructure development, and public health strategies is vital for building climate-resilient and sustainable cities that enhance the well-being of present and future generations.

Studies have shown that developing nations, including Nigeria, lack the accurate data needed to establish goals, strategies, and action plans for the protection of the challenges associated with the environment [9], [10], [11]. Thus, the rationale behind this research lies in the necessity for mitigation and adaptation interventions, which require the direct involvement of key climate change experts and other related professionals. The quantity and type of pollutants released into the atmosphere affect the composition of greenhouse gases and particulate matter, which in turn influence temperature patterns, precipitation levels, and overall climate dynamics. Therefore, understanding and mitigating the impacts of human activities on environmental balance and climate change are crucial for promoting sustainable development and preserving ecosystems.

The methodology employed in this study aims to document preventive measures within the context of climate change, with a focus on fostering environmentally regenerative practices in Nigeria's urban landscape. This empirical investigation seeks to uncover the influence of climate change on the urban landscape within the Southwestern region of Nigeria. The objectives are twofold:

(i) To identify drivers of climate change, and

(ii) To explore and evaluate adaptive strategies that leverage local ecological assets, to enhance energy efficiency and resilience in urban environments in the South-western region of Nigeria.

Therefore, the study's findings are significant in creating an energy-efficient urban environment that requires collaborative efforts from local government, urban planners, architects, engineers, and the community. It is, therefore, a must for policymakers to focus on initiatives that enhance the adoption of energy-efficient technologies, embed sustainability in urban planning frameworks, and create awareness of the importance of energy conservation. With investment in green technologies, improvement in public infrastructure, and implementation of comprehensive energy-saving programs, urban centres can reduce their ecological footprint, strengthen urban resilience, and create more livable cities. Similarly, by prioritizing environmental stewardship and adopting transformative approaches to sustainable development, communities can overcome the barriers to achieving the Agenda 2030 goals and create a more equitable, resilient, and thriving planet for all. In response to the challenges posed by UHIs, policymakers, urban planners, researchers, and community stakeholders in Nigeria are increasingly prioritizing sustainable urban development strategies that mitigate heat island effects while promoting climate resilience and an energy-efficient environment.

2. Literature Review

2.1 The Process of Urbanization and Changing in the Climate System

Authors Urbanization poses challenges such as congestion, pollution, and inadequate infrastructure, which require innovative solutions to ensure the well-being of urban populations and the sustainability of urban environments [8], [12]. This phenomenon has profound implications for resource consumption, environmental sustainability, and social equity. Nigeria's present growth rate is 2.62 per cent of the overall population and is not predicted to diminish beyond the year 2050 by 2.04 per cent [13]. Urbanization will have disastrous consequences for humanity and the preservation of landscapes in the upcoming decades [12]. Urbanization has spurred the proliferation of Urban Heat Islands (UHIs) in several Nigerian cities, with a notable concentration in the Southern regions [12], [14]. The Nigerian's total population density has witnessed a steady rise over the years, indicating increased human settlement and concentration. In 2004, the population density was recorded at 137.6 persons per square kilometre, which rose to 167.5 persons per square kilometre by the Year 2009, reflecting an annual growth rate of 2.5% [15]. Figure 1, depicts the temperature difference in degrees Celsius from 1900 to 2022 based on six data sets for Africa's 1991–2020 climatological period.

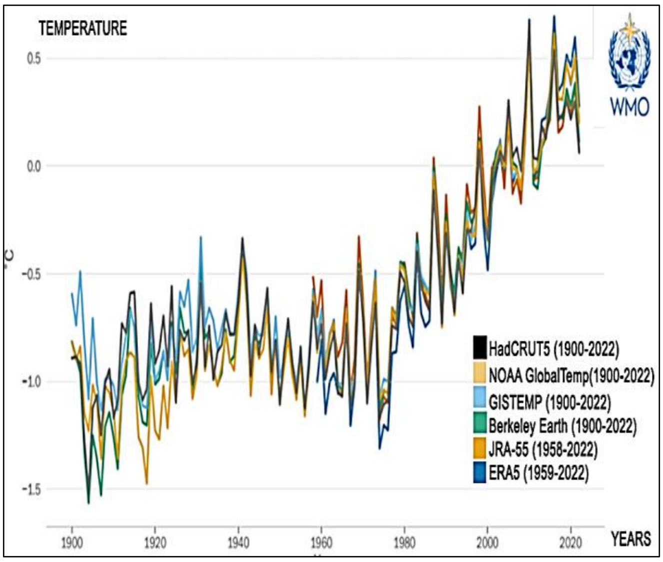

Fig. 1: African temperature difference in degrees Celsius from 1900 to 2022. **Source**: [43]

2.2 Energy-Efficient Built Ecosystems

Recent years have witnessed significant strides in energy-efficient building design that involve a paradigm shift from traditional approaches towards holistic and environmentally-conscious strategies aimed at reducing the ecological footprint of built environments on human health and natural ecosystems [16],[17]. Based on this ecological view, the concept of regenerative sustainability has become a core framework through which to address urban challenges with a specific focus on energy efficiency. A regenerative built environment is created based on structures and spaces that not only reduce energy consumption but also replenish resources to nurture the ecosystem. These programs essentially involve the planning and management of green spaces, urban forests, and natural landscapes in the urban setting to increase ecological function and facilitate environmental stewardship [18]. Integrated into urban planning, indigenous landscaping and green infrastructure can reduce the use of energy-consuming systems like air conditioners by creating better local microclimates and supporting natural cooling. These approaches also help preserve biodiversity, sequester carbon, and treat stormwater, further reducing the energy needs of urban areas.

By putting regenerative principles into focus, urban areas can strengthen their resilience to environmental stressors while raising the quality of life for all inhabitants. By adopting energy-efficient, sustainable materials, in combination with green roofs, solar panels, and advanced technologies in buildings, it supports the regenerative methodology by lessening the dependency on fossil fuels, reducing emissions, and enhancing energy conservation over the urban landscape. Further, it is within these international sustainability frameworks, such as the SDGs and the Paris Agreement, that have put a call to action on issues around climate change mitigation, biodiversity loss, and inequality. Adoption of the principles of regenerative design within built-up urban environments helps not only with global climate initiatives but also supports developments that are resilient, adaptive, and more energy-efficient. This holistic approach assists the evolving urban morphology in becoming better prepared for meeting complicated sustainability challenges in the coming future, which guarantees a built environment that does not simply reduce energy consumption but is actively proactive in the regeneration of nature. Figure 2 shows how urban and natural systems evolve toward a regenerative state. It emphasizes the connection between exergy use and waste formation. In which the system evolves toward sustainability and regeneration, as evidenced by an increase in exergy efficiency, structural order, and exergy accumulation and a decrease in entropy creation.

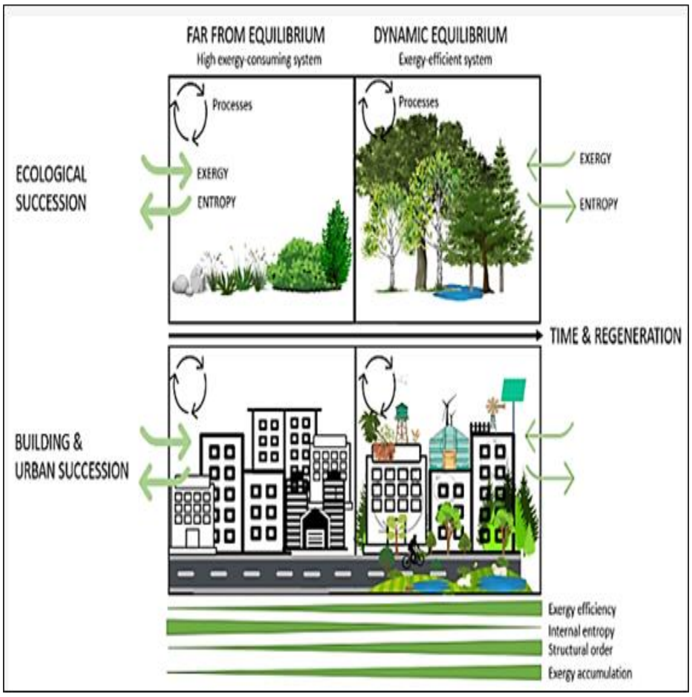

Fig. 2: Ecological and urban succession reducing entropy while increasing exergy efficiency, structural order, and regenerative system potential. **Source:** [45]

2.3 The Context of the Environmental Challenges

Environmental difficulties have culminated in ongoing rises in air temperature, thawing glaciers, increased sea levels, flooding, exhaustion, outbreaks of pandemics, and desert appearance. The causes of Nigeria's climate change were ascribed to a variety of environmental issues that had a detrimental impact on the country's space, particularly in the Southern regions. As long as climate change threatens the planet, problems like land degradation [19]; biodiversity loss [2]; pollution [17]; droughts [20]; deforestation/desertification [21]; urbanization [12],[14]; health issues [5]; among others will become worse. Moreover, human activities are a major driver of environmental degradation and deterioration. Activities such as deforestation, industrial emissions, and pollution from transportation contribute to the release of pollutants into the atmosphere, soil, and water bodies. These pollutants disrupt the balance of the environment and exacerbate climatic changes [17]. The presence of contaminants in a particular environment has a direct impact on its balance and can contribute to climatic shifts.

Sub-Saharan Africa's vulnerability to these adverse effects, with escalating temperatures and sea levels intensifying existing challenges was revealed by [22]. As climate conditions worsen, the health and safety of populations are increasingly jeopardized, underscoring the urgent need for proactive measures to mitigate climate-related health threats and help communities at risk become more resilient. Global environmental change is anticipated to cause malnutrition and impact negatively people’s health in South Asia and SSA regions [20], [23]. Similarly, [23], noted that the number of infectious diseases in people has increased compared with the period when there has been no climatic variability. With the current global warming of 1.2-1.9^{0}C predicted, food insecurity is predicted to rise by 25–90% in Sub-Saharan countries by 2050 compared to this current year. Figure 3, presents the EM-DAT global database on natural and technological disasters as revealed by [42]. It substantiates vital core data on the incidence and consequences of over 21,000 disasters in Africa.

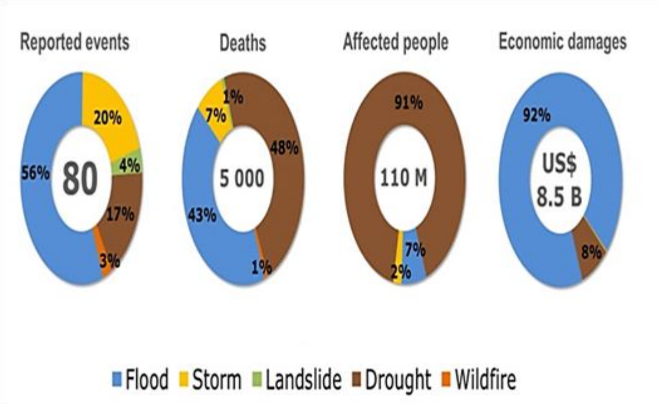

Fig. 3. Weather, climate and water-related disasters in Africa in 2022 for Emergency Event Database. Source: [44]

3. Theoretical Framework

This research employs a sustainable framework, highlighting methodologies that improve energy efficiency and promote resilient urban ecosystems. Key strategies recognized include the augmentation of urban tree canopies, the enhancement of functional green spaces, the application of innovative landscaping methods, and the restoration of wetlands. The integration of green infrastructure into urban design is highly important in terms of energy efficiency. Green building technologies and materials reduce energy consumption by enhancing insulation and reducing emissions, while functional green spaces and urban tree canopies create natural cooling systems that reduce reliance on artificial air conditioning. This integrated approach not only minimizes energy demand but also greenhouse gas emissions, thus making the urban environment more sustainable and livable.

The concept of resilience within the urban landscape is one of the most important focuses. The architectural and landscape design that accommodates extreme weather phenomena ensures that the urban regions keep their adaptability in response to climate change. Resilience-focused land-use planning enhances the capacity of the urban environment to deal with environmental challenges while encouraging sustainable development at the same time. Such strategies protect infrastructure and improve community well-being by reducing energy efficiency. As supported by [24]; the framework lays the groundwork for an environmentally sustainable paradigm. Additionally, the EPM framework emphasizes goal-setting, management, and citizen engagement through organized participation [25]. The framework was utilized extensively in several cultural and natural studies; while the conclusion drawn was based on sustainable landscape ecological planning that specifically intervenes with various biotic, abiotic, and cultural objectives (Figure 4). As depicted in the figure; a variety of ecological planning together with a regenerative paradigm drive, encompassed by a triangle that combines the abiotic, biotic, and cultural built environment concepts. The regenerative objectives for biotic, abiotic, and cultural resources are all rooted in individuals and address environmental issues associated with the built environment.

The framework effectively encapsulates key elements by emphasizing the value of adaptation, resilience, and regenerative resources, alongside the importance of sustainable landscape planning, ecosystem management, and public participation and engagement. This holistic approach underscores the necessity of addressing environmental challenges while promoting resilience and sustainability.

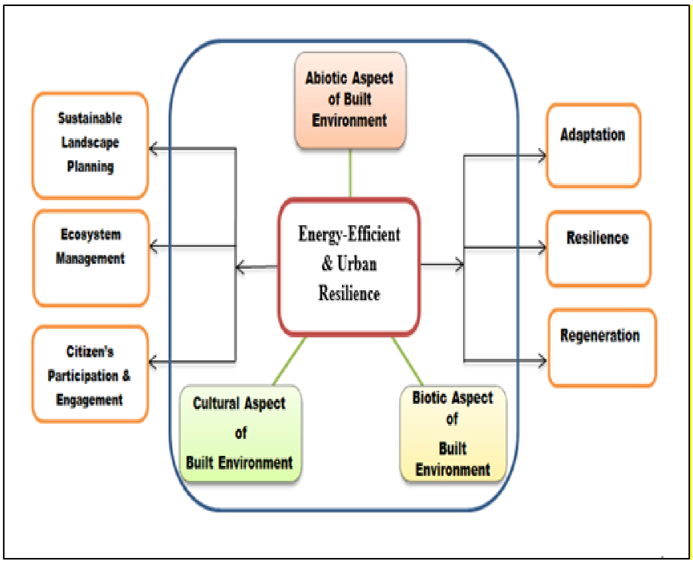

Fig. 4. The study's theoretical framework. **Source**: Authors' conceptualisation

4. Data Collection, Distribution, and Analysis

The Logistic regression analyses were conducted using the Statistical Package for the Social Sciences (SPSS) software package Version 22 to analyze the collated data from online survey distributions. Logistic regression is a statistical technique used to model the relationship between one or more independent variables and a categorical outcome variable. However, an initial pilot survey was conducted in September 2019 in the designated research areas to assess and refine the survey instrument's effectiveness and suitability. Feedback obtained from the pilot survey participants informed refinements to the main survey (between November and December 2019), enhancing its reliability and validity for subsequent data collection phases. Given the practical constraints and limitations in obtaining exhaustive lists of professionals within the built environment sector, convenience sampling was deemed a suitable approach for this study [26]. A total of 235 surveys amounted to 78.30 percent of the sample were gathered and examined. Cronbach's alpha coefficient (α)

and Composite Reliability (CR) are widely recognized methodologies for evaluating the internal consistency and dependability of an instrument. In this study, all variables demonstrated a high level of reliability, exceeding the minimum threshold of Cronbach's alpha coefficient (α) of 0.6, indicative of credible and consistent results. According to [27], reliability scores falling within the range of 0.6 to 0.7 are considered acceptable. The utilization of Cronbach's alpha not only enhanced the clarity and precision of the questionnaire instrument but also underscored the robustness of the data obtained. This rigorous testing procedure ensured the reliability and validity of the survey instrument, thereby bolstering the credibility of the study's findings and conclusions.

The Kaiser-Meyer-Olkin (KMO) measure of Exploratory Factor Analysis (EFA) sampling adequacy yielded a value of 0.706, which is considered acceptable according to [28], indicating the suitability of the questionnaire for factor analysis. Additionally, Bartlett's sphericity test was significant at the 0.001 level, further affirming the reliability of the latent constructs being analyzed. A threshold of 0.7 was utilized as the cutoff point for evaluating the adequacy of the factor analysis. In addition to assessing the psychometric properties of the questionnaire, demographic data for all 235 respondents were subjected to descriptive analysis. Beyond demographic data, respondents provided feedback on a set of 49 dependent measurement variables, evaluating their perceptions of climate change predictors and mitigation strategies. These measurement variables were adapted from previous studies. Participants' responses were scored using a 5-point Likert scale, with options ranging from "*Strongly agree*" (5) to "*Strongly disagree*" (1), providing a comprehensive understanding of their attitudes and perspectives regarding climate change predictors and adaptation strategies.

5. Results and Discussion

5.1. Demographic Characteristics

The demographic analysis of respondents presents a diverse group across various professions and backgrounds (Table 1). Among the respondents, 20% are environmentalists (47 respondents), 16% are educators (37 respondents), 19% are meteorologists or climate scientists (44 respondents), 14% are architects or urban planners (32 respondents), 14% are sustainability consultants (32 respondents), and 17% are public or environmental health experts (39 respondents). Regarding marital status, 25.6% of the respondents are single, 72.3% are married, and 2.1% are either divorced, separated, or widowed. Geographically, the respondents come from various states: 18% from Oyo (42 respondents), 10% from Osun (24 respondents), 10.0% from both Osun and Ekiti (24 respondents each), 23.0% from Lagos (54 respondents), and 21.0% from Ogun State (49 respondents); while 10% from Ondo (24 respondents) as shown in Figure 5. In terms of education, 10% of respondents have a high school education (23 respondents), 15% hold undergraduate degrees (35 respondents), 39% are graduates (91 respondents), and 36% have postgraduate qualifications (84 respondents). Professional experience is also varied: 45.7% have 1-5 years of experience (105 respondents), 28.6% have 6-10 years (65 respondents), and 25.7% have more than 10 years of experience (63 respondents). Out of 235 respondents, the majority, 126 (53.61%), rated themselves as "Very familiar" with Climate-Resilient and Energy-efficient Urban Landscapes. Meanwhile, 91 respondents (38.72%) indicated they were "Somewhat familiar." Only a small proportion, 18 respondents (7.65%), reported being "Not familiar at all" with the concept as shown in Figure 6. This shows that most participants have a moderate to high level of familiarity with climate resilience and energy efficiency in urban landscapes.

Table 1: Demographic characteristics of respondents

Demographic Variable	Category	Frequency	Percentage (%)
Gender	Male	124	53.0
	Female	110	47.0
Age	18-25	35	15.0
	26-35	65	28.0
	36-45	58	25.0
	46-55	42	18.0
	56 and above	32	14.0
Educational background	High School	23	10.0
	Undergraduate	35	15.0
	Graduate	91	39.0
	Postgraduate	84	36.0
Professional background	Environmentalists	47	20.0
	Educators	37	16.0
	Architects/Urban Planners	32	14.0
	Meteorologists/Climate Scientists	44	19.0
	Sustainability Consultants	32	14.0
	Public/Environmental Health Experts	39	17.0
Years of Professional Experience	1-5 years	105	45.0
	6-10 years	65	28.0
	11 years and above	63	27.0
	Oyo	42	18.0

Geographically states' affiliations	Osun	24	10.0
	Ekiti	24	10.0
	Lagos	54	23.0
	Ondo	24	10.0
	Ekiti	19	8.0
	Ogun State	49	21.0

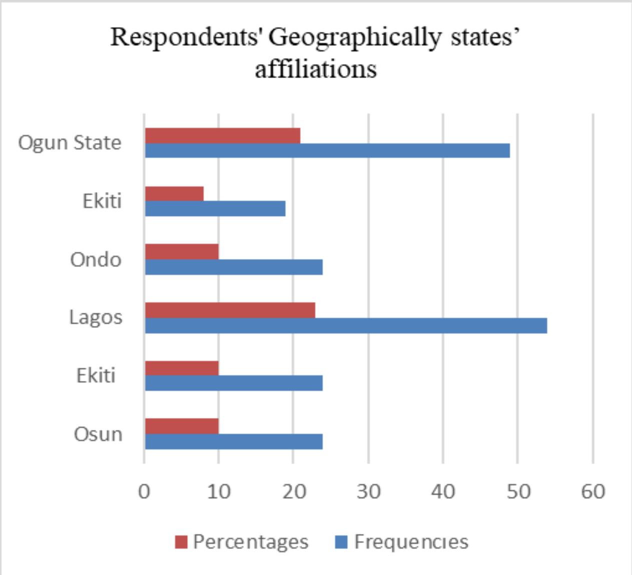

Fig. 5: Respondents' geographically states' affiliations

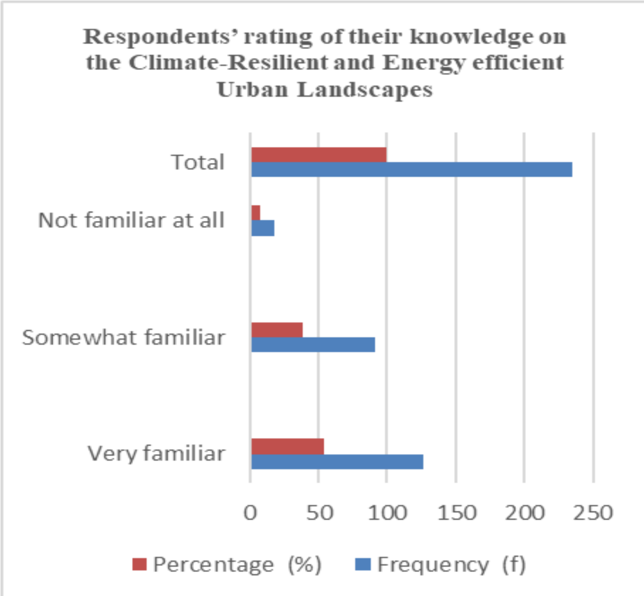

Fig. 6. Respondents' rating of their knowledge of the climate-resilient and energy efficient urban landscapes

5.2. Multivariate Regression

The factors that outweigh were found using Principal Component Analysis. Each item was made up of different variables that combined to generate a single variable with a designation based on content. Several independent variables were extracted for subsequent analysis using this method. The Pearson Bivariate Correlation Analysis was subsequently applied to assess the research variables' connections. This is to demonstrate the model prediction used for the result parameter. The findings of the statistical analysis of climate change drivers are presented in Figure 7. It revealed that climate change exhibits through degradation of land with a mean value of 4.25 and standard deviation (SD) of 0.52; biodiversity loss having a mean value of 4.23, and SD of 0.26; and pollution with a mean value of 4.07, and SD of 0.59. Others include drought with a mean value of 4.04 and SD of 0.52; deforestation /desertification with a mean value of 4.08, and a standard deviation of 0.46. In addition, urbanization exhibited mean values of 4.10, with a corresponding SD of 0.63; population growth with mean values of 4.09, and SD of 0.74. Overall, all these factors exhibited high mean scores.

On the contrary, transport disruption showed a mean value of 3.67, with a standard deviation of 0.64; health challenges showed a mean value of 3.84, and a standard deviation of 0.59; and Stratospheric ozone depletion had a mean value of 3.08, and a standard deviation of 0.57; were factors with low mean scores. Despite their lower average scores, these factors are confirmed to be predictors of climate change. The descriptive statistical results in Figure 8, demonstrated the highest mean scores of rise in the adverse effect of pollutants consequences had a mean value of 4.81 and standard deviation of 0.55; while the rise in the adverse effect of heat-related health consequences had a mean value of 4.85 and standard deviation of 0.52.

The rise in the adverse effect of mental-health consequences had a mean value of 4.94, with an SD of 0.23; the rise in the adverse effect of nutritional infectious consequences had a mean value of 4.83 and a standard deviation of 0.41; while the rise in the adverse effect in water borne related consequences had the mean values of 4.75 and standard deviation of 0.70. Lower mean scores, on the other hand, were recorded on the rise in the adverse shortages food production consequences with mean values of 3.82, and SD of 0.60; while the rise in the adverse effect of low level of economic-related consequences had the mean values of 3.85 and standard deviation of 0.51, and rise in the adverse effect of CO_2 emissions consequences had the mean values of 3.87, and SD of 0.42.

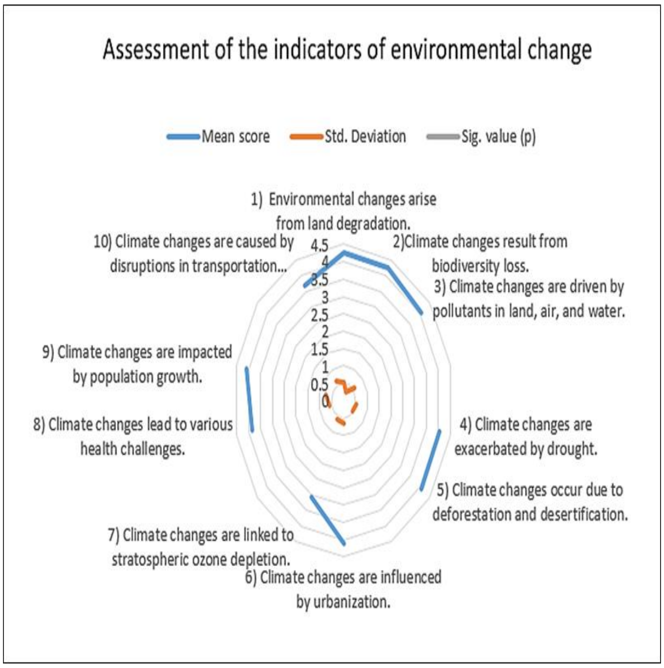

Fig. 7. Assessment of the drivers of climate change

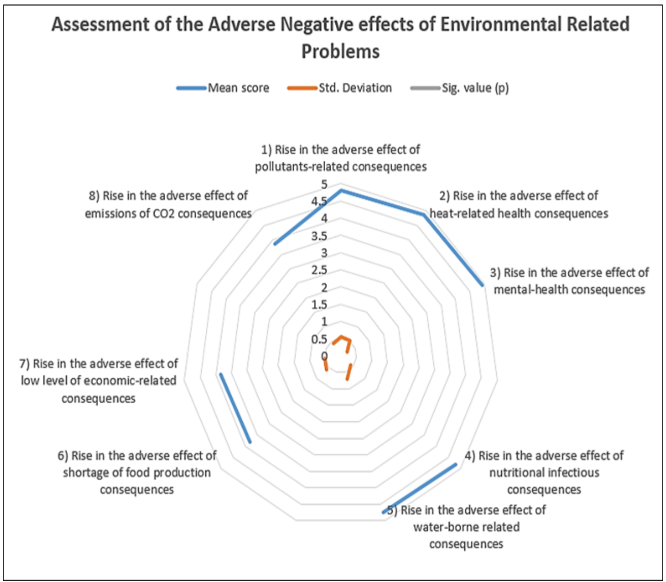

Fig. 8. Assessment of the adverse negative effects of environmental related problems

Table 2 was prepared using factor analysis, specifically principal component analysis (PCA), to examine respondents' backgrounds and drivers of climate change. First, the data set comprising various survey items was subjected to PCA, which extracted factors based on the correlation matrix. The initial eigenvalues represent the total variance explained by each extracted factor before any rotation. Kaiser's criterion (eigenvalues greater than 1) was applied to retain significant components. In this case, four components were identified: Component 1 (Demographics), ICC2, ICC3, and ICC4. The table shows each component's initial eigenvalue, the percentage of variance it explains, and the cumulative variance explained. Subsequently, the extraction sums of squared loadings were calculated, reflecting the variance accounted for by each factor after the extraction process, providing a more refined measure of the factors' contributions.

The findings of a Principal Component Analysis (PCA) indicated that the PCA is used to classify and identify significant components derived from a dataset. In this analysis, 49 variables were initially identified as important components. However, 19 variables were finally extracted; achieving four iterations of rotation with all having the eigenvalues exceeding 1. These collectively account for 86.99 per cent of the total variation in the data. The variance explained by these factors is distributed as follows: 26.45%, 21.22%, 18.63%, and 20.69% for each respective component. The initial component, also known as the 'Demographics', includes several variables such as education attainment, gender, age, academic history, employment history, and length of residency status. The second component called the 'Indicators of Changes in the Climate 2' (ICC2), consists of variables such as degradation of land, destruction of biodiversity, and pollutants. The third component, known as the 'Indicators of Changes in the Climate 3' (ICC3), considers characteristics such as severe weather, deforestation/desertification, and urban expansion. Also, the fourth key component, known as the 'Indicators of Changes in the Climate 4' (ICC4), includes variables such as ozone layer loss, health difficulties, population expansion, and transport disruption. This extensive investigation explores numerous aspects of climate change and its predictions, emphasizing the many dimensions that influence the dynamics of the environment.

The regression study of predictors of environmental changes influences on energy-efficient urban environment is presented in Table 3. The table displays standardized coefficients obtained from a multiple regression analysis. In this analysis, both the independent and dependent variables are standardized, meaning they are converted to z-scores with a mean of zero and a standard deviation of one. This process allows for a common scale to compare the effects of each predictor variable on the dependent variable. The standardized beta coefficient reflects the expected change in the dependent variable (measured in standard deviation units) for a one standard deviation change in the predictor variable while keeping all other predictors constant. Statistical software like SPSS automatically calculates these coefficients, along with their standard errors, F-values, and significance levels, which helps researchers evaluate the relative importance and influence of each predictor on the outcome variable.

However, the significance of predictors in the regression analysis is evident from the p-values. Specifically, the following variables were identified as significant predictors; Adoption of Renewable Energy Integration (β coefficient of 0.401;$p = 0.001$), Green Building and Sustainable Architecture (β coefficient of 0.367; $p = 0.002$), Promotion of Sustainable and Energy Efficient Transportation (β coefficient of 0.247; $p = 0.002$), Sustainable Urban Planning and Zoning (β coefficient of 0.350; $p = 0.003$) and Sustainable Energy-efficient Buildings (β coefficient of 0.202; $p = 0.004$). Additionally, Community-Based Ecological Solutions (β coefficient of 0.204; p = 0.012), ideas about operational green areas (β coefficient of 0.436; p = 0.003), the usage of indigenous flora (β coefficient of 0.499; p = 0.001), enhancing urban tree coverage (β coefficient of 0.467; p = 0.002), fostering thriving wetlands (β coefficient of 0.314; p = 0.001), Water Resource Management and Conservation (β coefficient of 0.470; p = 0.002), and Climate Resilience and Disaster Preparedness (β coefficient of 0.512, p = 0.003) were all found to be significant predictors. Moreover, the analysis reveals that usage of Indigenous flora holds the highest β coefficient of 0.480, succeeded by Water Resource Management and Conservation (0.470), enhancing urban tree coverage (0.467), and Operational green area (0.436), Climate Resilience and Disaster Preparedness (0.412), and fostering thriving wetlands (0.314), respectively.

The regression analysis reveals several important implications for enhancing the sustainability of built environments towards energy-efficient urban environments. One of the most significant findings is the dominant role of indigenous flora (β = 0.480), which emerged as the strongest predictor. This suggests that incorporating native plant species in urban landscapes is a key strategy for increasing ecological resilience. Indigenous plants, being adapted to local climates and ecosystems, require fewer resources such as water and maintenance, and they support local biodiversity. This highlights the crucial role of biodiversity in mitigating environmental impacts and fostering sustainable urban environments. The study also highlights the importance of water resource management and conservation (β = 0.470). Efficient water management systems and resilient infrastructure are essential for ensuring that urban areas can adapt to the increasing frequency of extreme weather events while safeguarding essential resources for future generations. The results also underscore the importance of enhancing urban tree coverage (β = 0.467) and maintaining operational green areas (β = 0.436). These factors significantly contribute to environmental sustainability by improving air quality, reducing urban heat, and creating healthier living spaces. Nature-based solutions, such as increasing green spaces and tree coverage, are essential to mitigating the urban heat island effect, which is exacerbated by climate change. By prioritizing these strategies, cities can reduce temperature extremes, manage stormwater, and improve the overall quality of life for residents.

The analysis further reveals the significant influence of the adoption of renewable energy integration (β = 0.401) and green building and sustainable architecture (β = 0.367). These findings highlight the importance of integrating renewable energy sources, such as solar and wind, into the built environment. Moreover, the adoption of sustainable architecture is crucial for reducing energy consumption and emissions. By employing energy-efficient design and sustainable materials, cities can move toward greener construction practices that support long-term environmental goals. These strategies are central to reducing the carbon footprint of buildings and promoting sustainability. The promotion of sustainable and energy-efficient transportation (β = 0.247) and sustainable urban planning and zoning (β = 0.350) are also significant predictors of sustainable built environments. Reducing reliance on carbon-intensive transportation through the promotion of electric vehicles, public transit, and pedestrian-friendly infrastructure is crucial for lowering emissions. At the same time, addressing urban heat through innovative materials and landscaping can help cities remain livable as global temperatures rise. These findings support the need for comprehensive urban planning reforms that prioritize both environmental sustainability and public health. Climate resilience and disaster preparedness (β = 0.512). These predictors indicate that cities must develop proactive strategies for conserving water and preparing for climate-related disasters such as flooding, droughts, and storms.

Finally, the significance of fostering thriving wetlands (β = 0.314) underscores the importance of preserving and restoring natural ecosystems. Wetlands act as natural buffers against flooding, improve water quality, and provide habitat for wildlife. By integrating wetland conservation into urban planning, cities can enhance their resilience to climate change while promoting biodiversity and ecosystem services. In conclusion, this study highlights the need for a comprehensive approach that combines nature-based solutions with technological innovations to create sustainable and resilient urban environments. The predictors identified in the regression analysis emphasize the importance of biodiversity, renewable energy, green infrastructure, and disaster preparedness in mitigating the effects of climate change and ensuring the sustainability of the built environment.

Table 2. Respondents' background and drivers of climate change

Component	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings**		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1 (Demographics)	12.328	39.691	38.582	5.723	26.45	34.782
2 (ICC2)	6.807	23.593	53.814	4.472	21.22	46.428
3 (ICC3)	1.266	22.188	48.871	3.253	18.63	63.512
4 (ICC4)	1.748	19.400	56.342	2.187	20.69	78.340

Table 3. The correlation between the environmental impact evaluations of respondents and the energy-efficient urban environment

Drivers	**Standardized Coefficients**		**df**	**f**	**Sig. value (p)**
	Beta coefficients	Estimate of Standard error			
Adoption of Renewable Energy Integration	0.401	0.028	2	3.019	0.001*
Green Building and Sustainable Architecture	0.367	0.021	3	3.622	0.002*
Promotion of Sustainable and Energy Efficient Transportation	0.247	0.005	3	2.200	0.002*
Sustainable Urban Planning and Zoning	0.350	0.088	2	3.001	0.003*
Sustainable Energy-efficient Buildings	0.202	0.070	3	3.893	0.001*
Community-Based Ecological Solutions	0.204	0.009	1	3.230	0.012*
Operational green area	0.436	0.016	1	5.207	0.003*
Usage of Indigenous flora	0.480	0.025	5	4.899	0.001*
Enhancing Urban Tree Coverage	0.467	0.203	4	5.492	0.002*
Fostering thriving wetlands	0.314	0.030	3	6.954	0.001*
Water Resource Management and Conservation	0.470	0.055	2	3.683	0.002*
Climate Resilience and Disaster Preparedness	0.412	0.068	2	3.100	0.003*

*Significant predictors ($p \leq 0.05$)

5.3. Predictors of Climate Change Strategy Indicators

The findings of this study have uncovered the various anticipated indicators of environmental change. These anticipated indicators are consistent with prior research by [21], [29]. The studies concurred with the fact that environmental climatic indicators pose serious threats to the ecosystem and sustainable cities in Nigeria. This climate change and ecosystem degradation include desertification, deforestation, floods, erosion, urbanization, and overpopulation [30], [31]. This study confirmed that significant loss and deterioration of natural ecosystems provide unmistakable evidence of indicators of impending environmental change. This degradation includes deforestation, habitat destruction, and ecosystem fragmentation, all of which contribute to the alteration of ecological processes and biodiversity loss, exacerbating the impacts of climate change. Additionally, the loss of natural

ecosystems often lead to a reduction in ecosystem services vital for human well-being, such as carbon sequestration, water purification, and flood regulation. These urban environmental issues will continue to be a menace to the sustainability initiative's goals, especially in developing countries if appropriate measures are not sought. The fact that desertification is mostly a man-made phenomenon that is exacerbated by climate change must be noted. As agreed by [19], further land degradation will come from an increase in weather extremes like drought and severe rain brought on by climate change.

Temperatures are rising, the land is drying up, and fertile soils are eroding across sub-Saharan Africa as a result of climate change, land degradation, and over-exploitation. This escalates catastrophic issues like starvation and severe droughts. In addition, biodiversity loss and increasing urbanization problems are linked to climate change, as demonstrated by earlier research by [2],[17]. Considering the importance of residents' health; the destruction of ecosystems has negatively impacted their health. This was in tandem with the findings of the previous studies by [20], [23]. Human health is being affected by climate change in Nigeria. Extreme weather conditions including droughts, heatwaves, and temperature increases have negatively impacted human health, which is in line with the previous studies [32].

Additionally, creating a sustainable environment is connected to urbanization, advancement of the economy, human capital development, and preservation of nature. Urbanization is intertwined dynamics of economic expansion, human progress, sustainable development, and preservation of biodiversity. These were complemented by earlier reports by [6],[31],[33]. In Nigeria, as populations concentrate in urban areas, there is a heightened focus on infrastructure development, resource utilization, and land management practices, all of which significantly influence environmental outcomes [31],[34],[35]. In connection to the transport system, pedestrian-friendly settings where fewer numbers of automobiles are used would continue to be one of the finest methods for decreasing cities' carbon footprints; while enhanced urban-rural links can assist in mitigating climate change [35],[36]. Sustainable urban planning and design can mitigate environmental degradation by promoting energy efficiency, waste reduction, and green infrastructure implementation. Furthermore, urbanization often correlates with economic growth, as cities become hubs for commerce, innovation, and employment opportunities. However, ensuring inclusive economic growth is essential to prevent disparities and enhance overall societal well-being. Investments in education, healthcare, and social services are critical for fostering human development and improving the quality of life in urban settings.

In parallel, urbanization presents unique opportunities for nature conservation. Strategically designed green spaces, urban trees, and playgrounds improve the area's aesthetic attractiveness, improve vital habitats for biodiversity, and contribute to ecosystem resilience. Integrating nature-based solutions into urban development plans can mitigate the adverse effects of urbanisation on natural ecosystems while promoting environmental sustainability. Summarily, urbanization acts as a catalyst for multifaceted transformations, presenting both challenges and opportunities for achieving sustainable development goals. Effective governance, stakeholder engagement, and innovative solutions are vital for urban landscape sustainability. A future approach to habitat sustainability is required with lower carbon dioxide emissions, minimal health-related issues; and a high-quality indoor and outdoor environment. Overall, the need for coordinated efforts toward mitigation and adaptation strategies arises from the fact that all climate change predictors present a significant challenge; and taking proactive efforts will lessen its adverse effects on raising the quality of life.

5.4. Adaptive Strategies to Enhance Energy Efficiency and Resilience in Urban Environments

With its diverse ecosystems, rapid urbanization, and vulnerability to extreme weather events, the need for sustainable development strategies has become increasingly urgent in Nigeria. In response, there is a growing interest in fostering regenerative practices within Nigeria's built environment to enhance climate change's adaptations. This study explores the concept of regenerative built environments in the Nigerian context and examines strategies for advancing climate change adaptation through sustainable urban development. Therefore, this study outlined the climatic conditions that pose significant risks to both inhabitants and ecosystems at large. Consequently, this study identified seven pivotal strategies for climate change mitigation and energy efficiency, drawing support from previous research by [1], [17]. These strategies include fostering environmental consciousness, maximizing operational green spaces, utilizing indigenous flora, expanding urban tree coverage, revitalizing wetlands, implementing smart landscaping practices, and embracing a biophilic approach. These measures are deemed essential for addressing the impacts of climate change effectively. Fostering environmental consciousness is a multifaceted strategy aimed at raising awareness, changing attitudes, and promoting behaviours that contribute to climate change mitigation and adaptation. This approach recognizes the interconnectedness of human actions and their impacts on the environment, emphasizing the importance of individual and collective responsibility in addressing climate-related challenges [36],[37]. This inferred that fostering environmental consciousness is a vital strategy for climate change mitigation and adaptation, as it empowers individuals, communities, businesses, and institutions to take proactive steps toward building a more sustainable and resilient future. By raising awareness, promoting behavioural change, advocating for policy action, engaging stakeholders, and enhancing community resilience, environmental consciousness can significantly impact how we handle the intricate problems brought on by climate change.

This study revealed that maximizing operational green spaces entails the deliberate integration of vegetation and natural elements into urban and industrial environments to enhance energy efficiency and resilience. This strategy in line with the study of [38], recognizes the multifaceted benefits of green spaces, including carbon sequestration, temperature regulation, stormwater management, biodiversity conservation, and human well-being enhancement. In tandem with the study of [19]; prioritizing green infrastructure investments, integrating nature-based solutions into planning and development processes, and fostering cross-sectoral collaboration, cities, and industries can leverage the power of green spaces to address the complex challenges posed by climate change and create a more resilient, and energy-efficient environment. The findings of this study underscore the potential for achieving sustainable communities through environmental greening and reduced reliance on motorized transportation, thereby contributing to a decrease in global carbon emissions as corroborated by the study [39].

This study highlights the role of native vegetation in making urban ecosystems energy-efficient by including indigenous plant species in landscaping, reforestation, habitat restoration, and ecosystem management practices. Native flora is naturally adapted to the local environmental conditions, such as temperature ranges, soil types, and precipitation patterns, which will enhance their ability to withstand climatic changes and thus reduce the need for costly energy inputs to maintain the landscape. Integration of native plant species into urban environments allows energy efficiency to be improved through natural cooling and shading processes, thereby reducing the use of artificial air conditioning and heating systems. It also supports carbon sequestration by indigenous vegetation, further taking some pressure off the urban carbon footprint and contributing to efforts to fight against climate change. This provides not only a more robust urban ecosystem but also supports biodiversity conservation, leading to long-term environmental and community benefits. Harnessing native plant species within a Green Infrastructure strategy is beneficial both in terms of reduced cost, maintenance, and resource consumption as a means of attaining an increase in energy efficiency; it also creates increased ecosystem resilience through the role that native plants play, finally preparing urban areas to develop sustainably with more potential to be resilient against climate-driven stressors.

Moreover, according to the results in [40], the focus on native species of plants in land management and restoration efforts strengthens ecosystem resilience, safeguards biodiversity, sequesters carbon, and supports sustainable development while respecting and conserving local ecological heritage. It is also critical that urban landscapes utilize native plants for energy-efficient environments because such species are already adapted to local climatic conditions, require less water, and need fewer maintenance activities, thereby reducing demand for energy-intensive resources. Increased urban tree cover can play a large role in energy efficiency: by providing shade, and cooling urban heat islands, the need for air conditioning in nearby buildings becomes less, therefore reducing energy consumption. In addition to that, urban trees bring relief to stormwater drainage systems, reduce urban flooding, and improve water quality by filtering pollutants before reaching water bodies.

Notably, urban green spaces with a dense tree cover provide recreation opportunities, cultural amenities, as well as aesthetic value, hence improving the quality of life among the citizens of a metropolitan area. Such places are vital in enhancing environmental quality and stimulating sustainable urban development. As stated by [41], municipalities that emphasize tree planting and investment in green infrastructure can enhance resilience in the cities while creating a less energy-consuming environment. They have several ecological, social, and economic benefits, hence consideration in the development of sustainable and resilient communities. This would raise an increasing call for the adoption of a biophilic approach to bring in ecological resilience and alleviate the consequences of climate change. In addition, incorporating natural elements into urban designs, such as natural lighting, plants, water features, and views of nature, could significantly improve energy efficiency. As pointed out by [42], biophilic design emulates natural ecosystems and increases human well-being and happiness by fostering a relationship with the natural world. Also, integrating biophilic principles into urban and architectural settings can stimulate community interaction, provide open outdoor areas that are accessible, and offer social spaces for activities, recreation, and cultural events all of which reinforce a sustainable and energy-efficient urban environment.

6. Conclusion

The contribution of this study shows that adaptive strategies using local ecological assets, such as native plant species and green infrastructure, provide a feasible manner of achieving energy efficiency and resilience. By integrating these strategies into urban planning and design, municipalities can address climate-related challenges while enhancing ecological health, social well-being, and economic vitality at the same time. These methodologies not only reduce environmental impacts but also foster a more sustainable future for both urban and rural communities. This research employs a sustainable framework, highlighting methodologies that improve energy efficiency and promote resilient urban ecosystems. Key strategies recognized include the augmentation of urban tree canopies, the enhancement of functional green spaces, the application of innovative landscaping methods, and the restoration of wetlands. These interventions are meant to mitigate the adverse effects brought about by urbanization and align with the SDGs, specifically Goal 11 (Sustainable Cities and Communities), Goal 13 (Climate Action), and Goal 15 (Life on Land). With a focus on sustainability, these goals address high-priority environmental concerns and long-term urban resilience.

The integration of green infrastructure into urban design is highly important in terms of energy efficiency. Green building technologies and materials reduce energy consumption by enhancing insulation and reducing emissions, while functional green spaces and urban tree canopies create natural cooling systems that reduce reliance on artificial air conditioning. This integrated approach not only minimizes energy demand but also greenhouse gas emissions, thus making the urban environment more sustainable and livable. The preservation of native plant species and restoration of wetland areas form integral parts of this methodology. In maintaining biodiversity and reinforcing the ecosystems, these initiatives inherently stabilize urban temperature fluctuations, enhance air quality, and develop habitats for indigenous species. Wetlands, in particular, are important regulators of stormwater and flood impact reduction, hence strengthening both ecological and urban resilience. Through the incorporation of these environmentally conscious approaches, the research highlights the significance of merging ecological conservation with energy-efficient and resilient urban design. Such initiatives not only protect Nigeria's natural heritage but also establish a foundation for improving urban sustainability and responding to forthcoming environmental challenges.

The findings of this study have shown the need for collaboration among Nigerian policymakers, educational administrators, instructors, business people, and researchers to initiate a campaign to create awareness in the country of climate change and its impact on energy efficiency in urban areas. Further collaboration among governmental, para-governmental, and non-governmental organizations is thus indispensable to encourage the formation of climate-resilient infrastructure that enhances energy efficiency in urban areas for sustained urban development. For instance, the Nigerian Government's National Climate Change Policy and Response Strategy should integrate specific measures to improve energy efficiency in the built environment while, at the same time, building resilience to the effects of climate change.

In addition, the professional bodies should be advised: the Nigerian Institute of Architects and the Nigerian Society of Engineers; to adopt building standards or regulations that prescribe energy efficiency within construction methodologies. These can help in making buildings use less energy and enable the provision of lower emissions and other structures that have been engineered to respond fittingly towards the challenges faced due to climate change. Moreover, the application of efficient innovations in adaptation and mitigation strategies should be one of the major focuses while upgrading human capacities and infrastructure energy efficiency. This is in line with the National Adaptation Plan (NAP) adopted by the Nigerian Federal Ministry of Environment in 2020, which called for collaborative efforts in addressing the energy challenges presented by climate change. In this regard, regional training workshops are needed to build the capacities of stakeholders so that they can integrate energy-efficient measures into state development plans. The study, however, is mindful of some limitations, including the lack of meteorological data in the study region and the non-existence of comprehensive databases of experts in the built environment. Despite these challenges, the study marks the requirement for good policy and practice designs to improve energy efficiency and reduce climate change in urban Nigeria.

A future research project-based case study proposed in this study focuses on implementing and evaluating adaptive strategies for enhancing energy efficiency and resilience in Nigeria's urban landscapes. For example, a pilot project could be conducted in a densely populated Lagos neighbourhood where environmental challenges are acute. The study would begin with a baseline assessment of energy consumption, building performance, and the existing state of green infrastructure. Subsequently, adaptive interventions such as integrating indigenous flora, installing green roofs, and retrofitting buildings with energy-efficient Technologies would be implemented in collaboration with local authorities and community stakeholders. This case study would offer practical insights into the real-world impacts of adaptive strategies, serving as a model for similar initiatives in other developing urban areas.

Conflict of Interest

The authors declare that they have no conflicts of interest.

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