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Environmental Sustainability: E cological Footprint Analysis ofI badan North, Nigeria

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Abstract: The ecological implications of global development have been a primary focus in discussions surrounding sustainability. As urban development expands globally, addressing its many ecological concerns becomes imperative. However, the ecological footprint (EF) analysis of urban sustainability within the sub-Saharan region, particularly Nigeria, remains largely unexplored. Here, we used the EF indices to explore the environmental sustainability of Ibadan City, one of Nigeria's fastest-growing urban centres. We implemented a bottom-up EF approach in the study, employing a cross-sectional design. We used an EF questionnaire to gather monthly household consumption data on food, energy, and water. We analysed these data descriptively and methodologically using EF formulae. Findings indicate environmental sustainability, as reflected in the low EF of 0.43gha/capita, with the energy footprint accounting for the majority (93%) at 0.4gha/capita. In comparison, the food footprint had the lowest share (below 3%) at 0.01gha/capita. Our findings demonstrate the significant impact of energy consumption on the overall EF, reinforcing the need for more sustainable energy solutions in urban planning, thus contributing to urban sustainability by informing urban planning and energy policy in alignment with the global sustainability drive.

Keywords: ecological footprint, environmental sustainability, urban sustainability, sustainability, Nigeria

1. Introduction

Today, the world faces increasing environmental and public health challenges, with global sustainability being a pressing issue for developed and developing nations. This stems from the unsustainable utilisation of natural resources resulting from rapid urbanisation and population growth, driven by the escalated demand to meet human needs. Evidence indicates that over 55% of the global population presently resides in urbanised regions and is expected to climb to 68% by 2050 [1], emphasising the relevance of urban centres as the focus of sustainability evaluations [2]. As a result, the necessity to estimate the utilisation and exploitation of ecological resources has given rise to sustainability and, by extension, sustainability indicators.

Interestingly, there has been a proliferation of indicators to measure environmental sustainability in recent decades. Among these approaches, the ecological footprint (EF) tool has emerged as one of the most extensively used methods. Rees and associates initially developed it to assess the inherent urban sustainability of entire nations [3]. This presents a well-defined standard to determine the extent of human reliance on nature concerning the provisions nature offers to humans (bio-capacity). For instance, assessments of the EF suggest that the current human demand exceeds the bio-capacity by over 60% [4, 5], with over half of the world's nations already on ecological deficits, utilising more bio-capacity than is available within their limits [6]. More so, according to the report by the Global Footprint Network (GFN), supporting the existing lifestyle and consumption, humanity needs approximately 1.7 Earths [7]. This suggests increased ecological strain as urbanisation expands [8], thus underscoring the necessity for EF assessments of urban sustainability, considering the increasing prominence of the latter in the global pursuit of sustainability.

A comparative study by Zhiying and Cuiyan [9] in China sheds light on how analysing EFs can reveal the environmental pressures caused by household consumption in rapidly developing economies. Their findings emphasise a growing pattern of ecological deficits caused by rising per capita consumption and stable or decreasing ecological carrying capacities. Similarly, Fuju et al. [10] explored the Yellow River Delta in China, finding that despite efforts to improve EF, the area faced significant ecological deficits due to unsustainable resource consumption practices. More so, a recent study by Goldstein et al. [11] highlights the significance of considering local environmental conditions when implementing global sustainability frameworks. Their findings indicate that EF analysis is helpful, but it needs to be tailored to the socio-economic context of regions like Ibadan North to achieve maximum effectiveness. Thus, these studies highlight the significance of incorporating EF analysis into urban and regional planning and policy-making, especially in rapidly growing urban areas like Ibadan North, where resource demand is increasing.

However, while the EF evaluation has achieved significant application nationally [12, 13], there is a dearth of assessment at the city level globally [14, 15], particularly in developing countries, because unlike national and regional datasets which are readily available and standardised, city-specific data on resource consumption are often scarce [14, 16]. The lack of local data and the absence of city-specific EF analyses hinder the ability to develop targeted, evidence-based, sustainable urban policies, considering the impact of cities on sustainable development. This gap underscores the need for the present study to bridge this knowledge deficit by providing an EF assessment of Ibadan North, given its status as a rapidly expanding urban centre in Nigeria. By leveraging local population-based consumption data and the EF analysis tool, this study offers critical insights into the sustainability of urban consumption in Ibadan North, Nigeria.

Therefore, our study on Ibadan North addresses the broader global challenges by examining the impact of local consumption patterns on ecological sustainability. By applying the EF model, the study evaluates the sustainability of existing practices. It presents valuable insights into how similar challenges in urban centres and other regions have been tackled. As a result, this study aims to evaluate the EF of Ibadan North City in Nigeria, focusing on identifying the primary factor that contributes significantly to the overall EF and its implication for environmental and urban sustainability. The findings will have a dual impact, informing both urban planning and policy-making while laying the groundwork for developing future scenarios for comparative analysis.

The next section of the paper presents the method, which encompasses the gathering and analysis of data. Following this, the key findings of the study are outlined. Last, we discuss the significant findings and their implications, acknowledge the study's limitations, and conclude by providing key policy recommendations.

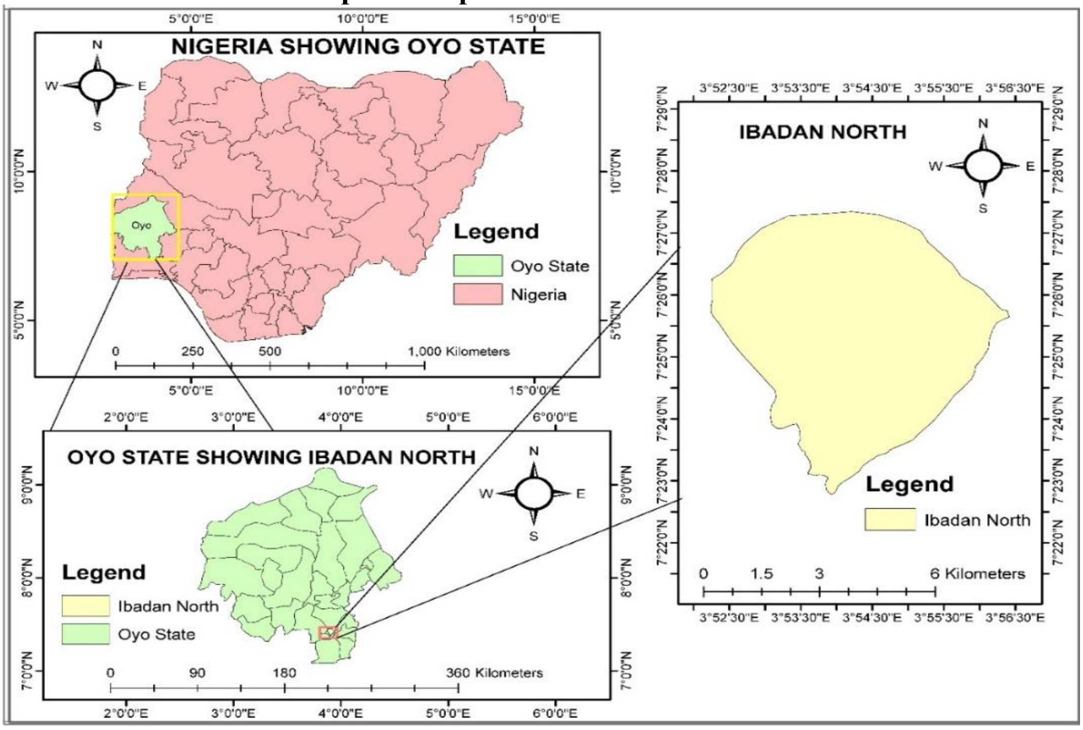
2. Methodology

2.1 Study area

The study was conducted in Ibadan North, one of the five urban Local Government Areas (LGA) of Ibadan Metropolis. It is one of the fastest-growing urban cities in Nigeria, making it an appropriate choice for this study. It is a densely populated urban LGA with a population of 306,795, based on the 2006 national census report. Moreover, a recent estimate by City Population places the population at roughly 440,400, with a 2.3% annual growth rate. Ibadan North, which has an area of 27 km^2 [17], borders the LGAs of Akinyele in the north, Ido in the west, and Ibadan North East in the east.

Located in the Guinea savannah, Ibadan North, one of the urban areas comprising the Ibadan metropolis, has a typical West African monsoon climate with distinct rainy and dry seasons (rain: March and October and dry: November and February). As a result, the region is naturally a belt with a mixture of tall grasses and trees in the South and shorter grasses and fewer trees in the north. According to Olanrewaju et al. [18], Ibadan's vegetation comprises extensive areas of forb vegetation, dense thickets, savannah woods, and fragmented forest. When vast tracts of land are available on the urban periphery, farming is typically done as plantation agriculture, livestock husbandry, or settlement farms [18].

Figure 1
Spatial map of Ibadan North LGA



2.2 Study design

We employed a cross-sectional survey approach to assess the EF of Ibadan North and provide a status shot of the study area's annual material consumption. We used the EF questionnaire adapted from studies by Khan and Hussain [19] as well as Khan and Uddin [20] to gather data on energy and food consumption from 384 households in the study area (see Table 1). Additionally, secondary data (such as the yield factor, equivalent factors, and others) were derived from organisations such as the Food and Agricultural Organisation, Global Footprint Network, National Population Commission, Ibadan Electricity Distribution Company (IBEDC), and other web-based publications (see Table 2).
To assess the validity and reliability of the study instrument, we carried out a pilot survey consisting of 20 households in Oyo West LGA, a comparable urban city to the study area, before the primary household survey to guarantee the validity and reliability of the survey instrument. This proved helpful because the preliminary instrument was updated to take observations into account, improving its accuracy in gauging the different consumption patterns of households for the EF estimation. Additionally, utilising SPSS version 23.0, a Cronbach's alpha reliability test was conducted to guarantee the dependability of the study tool. The findings (0.73) indicate that the internal consistency of the study instrument is suitable. In turn, this enhances the study's overall credibility and enables the drawing of trustworthy conclusions regarding the sustainability and EF analysis of Ibadan North.

Consequently, a sample size of 384 households was randomly selected for the study using Tara Yamane's method for sample size determination (Eq. 1) at an error margin of 0.05 and a 95% confidence interval. The sample size estimated for the study is adequate to give a good representation of the population of the Ibadan metropolis, which was estimated to be 440,400 in 2022 (City Population, 2024).

$$\mathbf{n} = \frac{N}{1 + e^2} \quad (1)$$

where, n = sample size. N = population under study, and e = margin error

We adopted a stratified sampling technique due to the nature of the study area. We divided the study area into 13 political wards and randomly selected five wards to determine the samples. We then systematically distributed 77 questionnaires across the five selected wards. We selected the final sample with households sampled systematically at intervals of every fifth house in each selected ward until the desired sample size was achieved.

2.3 Method of Data Analysis

In this study, we analysed the data in two ways. The descriptive analysis involved a distribution table, with simple percentages analysed using Microsoft Excel to summarise the quantitative data. Consequently, the consumption category with the most significant footprint contribution for sector-specific EF intervention can be identified by comparing the percentage contribution of each consumption category to the overall EF of the study area. The inferential analysis employed EF mathematical models adapted from Fadeyibi et al. [21] for EF calculations.

Table 1
Considered components of energy and food derivation of EF

Food	Cereals	Beverages	Fish	Fruits	Meat/Poultry	Confectionaries	Vegetables
Water	Laundry	Bathing	Kitchen	WC	Drinking	-	-
Energy	Electricity	Gas	Kerosene	Firewood	Charcoal	Generator	-

Table 2
EF data requirements and sources

S/n	Data	Source
1	Demographic Data	Field Survey
2	Population	City Population [22]
3	Footprint Consumption Data	Field Survey
4	Energy/Kwh	IBEDC
5	Yield Factors	Global Footprint Network [6]
8	Equivalence Factors	Global Footprint Network [6]
9	LPG price/Kg	Beta price

2.6 Determination of EF

This study adopted a bottom-up or component-based approach, distinguishing it from the top–down approach using local population consumption data. Studies by Khan and Hussain [19] as well as Khan and Uddin [20] employed a similar approach. However, considering the use of data generated through a bottom-up analysis is of particular importance. This approach provides first-hand information directly from the country's population rather than relying on statistical databases. As such, local authorities can better understand urban and environmental sustainability, focusing specifically on the Ibadan metropolis - one of Nigeria's fastest-growing cities. However, given limited resources and time, our study focused on the EF of energy and food because prioritising energy and food footprints allows the study to make valuable contributions in areas where intervention can lead to significant environmental benefits, thus setting the stage for future studies to expand into other EF sectors.

The estimated EFs are compared against the EF benchmark to determine sustainability. According to [23, 24], an EF value (gha/capita) less than one is considered a marker of sustainability, indicating if a given population uses natural resource flow without damaging resource assets, thus ensuring that human activities do not surpass the earth's ecological capacity.

Consequently, for the present study, we used the approach described by Fadeyibi et al. [21] for the EF determination, as follows.

2.6.1 Energy footprint estimation

We employed the greenhouse gas (GHG) conversion standard (2010) to assess the energy footprint, encompassing six distinct energy sources: electricity, generators, kerosene, gas, firewood, and charcoal. We quantified the energy accumulated during the field survey in kilowatt-hours (kWh). Since one kWh (during the reference period) was valued at N56.40 Nigerian Naira according to the IBEDC, we converted the total energy from each source to kWh by dividing the amount by N56.40 naira. The energy value for electricity was then calculated in MJ by dividing the energy value in kWh by 0.2778 kWh [21]. We used the revised GHG emissions of different fuels for 2019 to compute the embodied energy in MJ/Kg and $C0_2$ emissions in Kg/MJ. Subsequently, the energy value in MJ was then divided by the national yield factor for forest land (0.26) [6], multiplied by the equivalency factor (1.29) [6], CO_2 emissions (kg/MJ), and the resultant value was divided by the total population value of Ibadan North, to estimate the energy footprint in gha/capita.

$$\boldsymbol{EF_e = \sum_1^6 \frac{EV}{Y_f} \times E_f \times CO_2\ gas\ emission\ \frac{kg}{MJ}} \quad (2)$$

Where EFe = EF of energy usage (gha/capita), CO_2 *Emission* = CO_2 emission (kg/MJ), *EV* = Energy Value (MJ/kg); and E_f *and* Y_f = equivalence and yield factor, respectively.

2.6.2 Food footprint estimation

The empirical survey yielded an estimate of the annual food consumption. We calculated the consumption in kilograms by dividing the yearly consumption cost by the average price of 1 kilogram of food, recorded as 650 Nigerian naira in the market survey. We divided the consumption in kilograms by 1,000, allowing for the conversion to tonnes. As a result, the calculation of the EF in global hectares required dividing the consumption in tonnes by the national yield factor of cropland (0.93) and then multiplying the resultant value with the equivalence factor (2.50) and the embodied energy of food consumed in tonnes. Later, the EF per capita was derived by dividing the global hectare footprint by the Ibadan North population, estimated to be 440,400 inhabitants according to the City Population [22]. The outcome of this calculation yields the per capita global footprint in hectares, as denoted by Eq. 3.

$$\boldsymbol{EF_f = \sum_1^7 \frac{C}{Y_c} \times E_f \times EE} \quad (3)$$

Where**;** EF_f = EF of food (gha/capita); *C* = food consumption in tons; *EE* = embodied energy (MJ/kg); and E_f *and* Y_f = equivalence and yield factor, respectively.

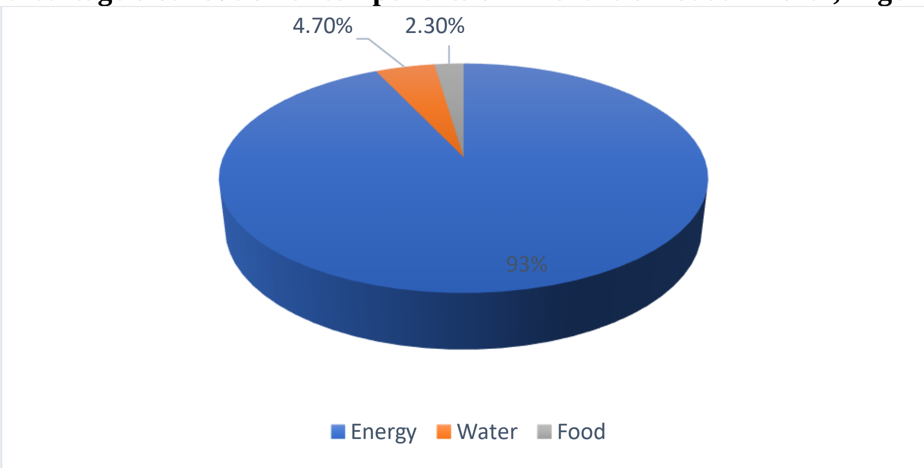
3. Results and Discussion

The study examines EF of Ibadan North, Nigeria, by exploring the sustainability of energy and food consumption. Findings the EF of Ibadan North to be 0.43gha/capita, which is slightly equivalent to the national bio-capacity of 0.4gha/capita [23], suggesting sustainable consumption, as consumption by the people is well within the means of nature. The result indicates that the residents will need almost the equivalent of Nigeria should Nigerians consume at this rate, as evidence suggests that EF is unsustainable when the calculated value is more than one [24, 25]. The present findings may be unconnected with the recent economic hardship in the country, which may have impacted the spending and consumption capacity of the people. Studies have documented similar findings in Minna [24], which aligns with the current findings and highlights the need to promote sustainable economic policies to facilitate improved economic conditions while ensuring sustainable consumption.

Moreover, the breakdown of the EF components highlights the dominance of the energy footprint (0.4gha/capita), which accounts for 93% of the total EF share (see Figure 2). The findings confirmed that energy consumption, especially from generators and electricity, was the main contributor, as anticipated, highlighting the significant impact of energy consumption on the EF of the study area. The high energy footprint is due to the widespread reliance on generators in response to the unreliable electricity supply in most Nigerian cities. These generators are known for their high carbon emissions [26, 27], contributing significantly to the EF [28].

Thus, addressing the current energy consumption pattern will significantly reduce its EF and ensure environmental and urban sustainability. Previous studies have documented energy footprint as a significant contributor to EF [29, 30], further validating the current outcome. However, the current findings contrast with those of Otto et al. [31], who reported energy footprint as the second major contributor to the EF share of Ijebu Ode. The disparities in the results may have been caused by the variation in the energy consumption pattern, with residents utilising more clean and sustainable energy sources in electricity and gas, which are known for having a lower EF impact [32, 33].

Figure 2
Percentage distribution of components of EF share of Ibadan North, Nigeria

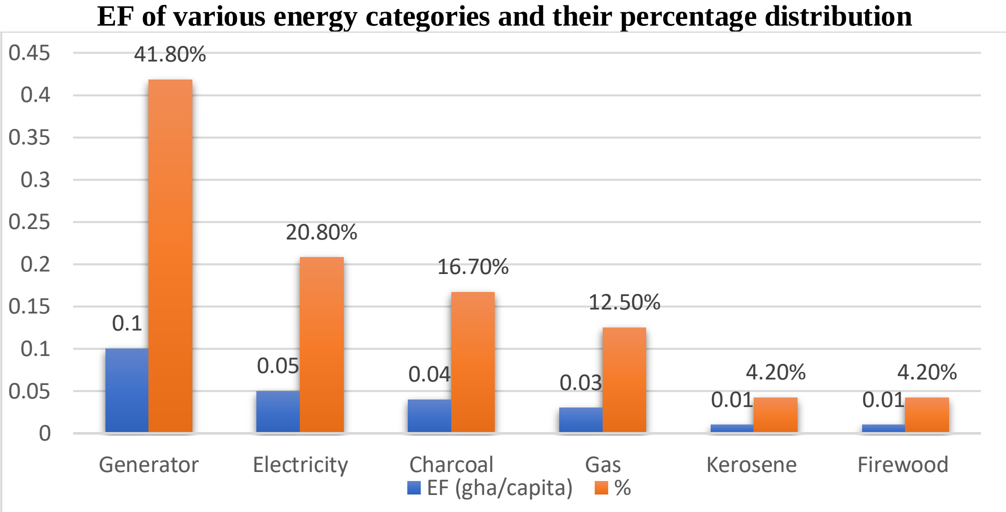


Similarly, examining the distribution of the energy footprint among different sources sheds light on crucial contributors and areas for potential improvement. The results revealed that generator usage contributed the most to the energy footprint share (Figure 3), with an EF of 0.10gha/capita (41.6%) of the total. This finding underpins the significance of off-grid energy sources, such as generators, in meeting energy needs in the region. However, reliance on generators also raises concerns about carbon emission and fuel consumption, highlighting the importance of transitioning towards cleaner and more sustainable energy alternatives.

Unsurprisingly, kerosene with 0.01gha (4.2%) and firewood with 0.01gha (4.2%) represent the lowest contributors to the energy footprint (see Figure 3), which portends a low impact on EF due to their high carbon contributions. A possible explanation for these results may be linked to the high kerosene cost occasioned by subsidy removal, signifying low demand. This finding is consistent with previous studies documenting the firewood and kerosene footprint as having the lowest effect on Bida's overall energy footprint [34]. Thus, it suggests a shift from fossil fuel-based sources to clean and sustainable energy sources to ensure sustainable energy consumption while promoting the country's green energy ambition.

Notably, a careful observation indicates a substantial energy contribution to the EF, suggesting that energy consumption, particularly with generators, significantly impacts EF in cities with unstable power systems. Thus, it stresses the importance of improving energy infrastructure and promoting energy-efficient practices to reduce EFs in comparable urban regions. As such, our findings highlight the significant influence of energy usage on the overall EF, underscoring the necessity of incorporating sustainable energy solutions in urban development.

Figure 3

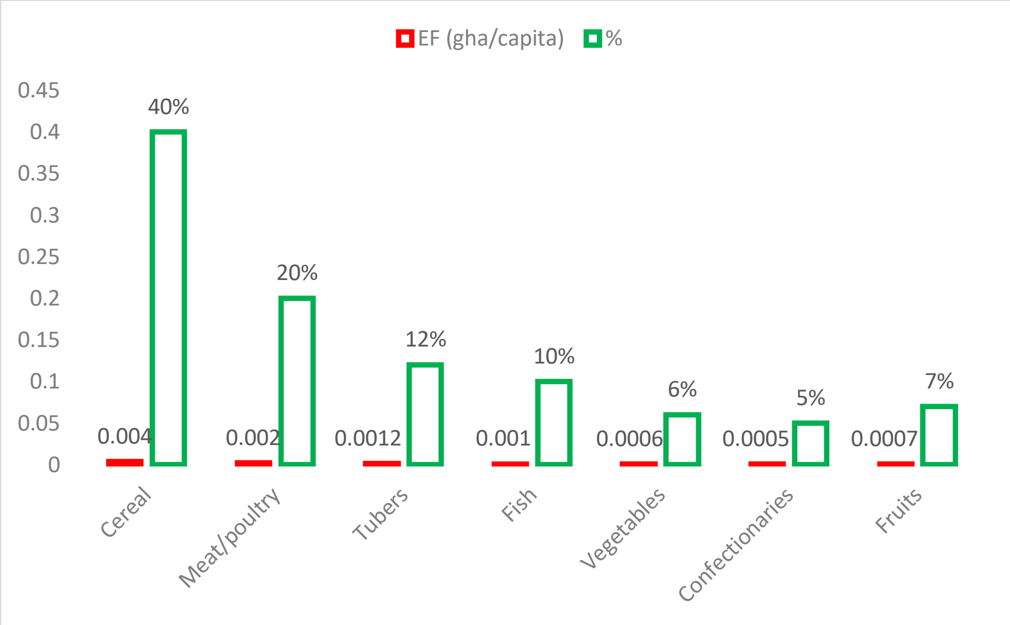


Surprisingly, secondary results show that the food footprint represents the lowest proportion (0.01gha/capita), less than a 3% contribution. The unexpectedly low footprint of food consumption suggests a relatively sustainable pattern, especially in urban areas where food production and consumption are usually resource-intensive. This implies that overall, food consumption in the area is sustainable, which is encouraging from an environmental standpoint. The low food footprint could be the prevalence of locally sourced, plant-based diets, which generally have less ecological impact than diets rich in animal products. The high cereal consumption, known for its low environmental impact [35, 36], supports this claim. The current finding is consistent with studies in rural or less urbanised regions, indicating that the practice of agriculture and consumption of locally sourced food has a substantial impact on reducing their food footprint [24, 37, 38]. For example, a study in China compared the EFs of food in urban and rural areas. The findings showed that rural regions generally have lower footprints due to lower food consumption and dietary habits less dependent on resource-intensive foods such as meat [39]. However, in contrast to studies in more developed regions [11, 40], where the food footprint accounts for a more significant proportion of the total EF, the findings for Ibadan North show a stark difference, with energy consumption dominating the footprint. The variation in infrastructure and dietary habits is probably the reason behind this variation. Another explanation for this inconsistency may be attributed to the high consumption of processed food, with evidence suggesting that highly processed food significantly contributes to EF [41, 42], underscoring the significance of rural lifestyles in maintaining lower EFs and suggest that policy interventions should focus on sustaining these practices while ensuring food security and nutritional adequacy.

Additionally, closely observing the EF distribution among different food categories highlights some trends. Cereals emerge as the category with the highest footprint share (0.004gha), accounting for 40% of the total food footprint (Figure 4). This finding highlights the significance of cereals in the local diet. It emphasises the need for sustainable agricultural practices in cereal production to mitigate the footprint of food consumption in the study area. Studies have shown that cereals contribute significantly (70%) to the household food consumption demand in Nigeria [43], particularly in the southwestern region [44] of the study area. It suggested that cereals have a lower contribution to EF [36] as a plant-based food source, which, in contrast to animal-based food, has lower GHG emissions [45, 46], hence low EF. The finding agrees with previous observations by Khan and Uddin [20] as well as Zhen and Du [35], who documented cereal as having the highest food footprint component. These findings underscore the role of dietary choice and households' food consumption patterns in fostering EF.

Overall, the low food footprint suggests sustainable practices, which could be applied to other developing cities with similar socio-economic conditions, highlighting the need for further investigation into sustainable consumption practices in similar contexts, which will contribute to a broader understanding of EFs in developing countries.

Figure 4
EF of various food categories and their percentage distribution



Furthermore, meat and poultry follow cereals with a footprint share of 0.002gha (20%) (see Figure 2), indicating their contribution to the overall EF of food consumption. Given the environmental challenges associated with livestock farming, such as land use and greenhouse gas emissions, efforts to promote sustainable meat production and consumption could help reduce the EF of this category. Conversely, confectionaries, vegetables, and fish exhibit lower footprint shares, each contributing less than 10% to the total food footprint. While these categories may have relatively lower EFs than cereals and meat, attention to sustainable production and consumption practices remains essential to ensure their continued contribution to a more environmentally friendly diet.

Notably, global environmental sustainability has been a critical priority target for all national governments, emphasising sustainable consumption and underscoring the timely relevance of this study, especially from the Nigerian context. Thus, the study makes significant contributions to existing knowledge by providing empirical evidence of the environmental sustainability of Ibadan North, Nigeria, as the first attempt to assess the EF of one of Nigeria's megacities, thus helping local governments understand its urban and environmental sustainability, contributing practical-based information on Nigeria's urban sustainability for future references. More so, our findings reveal the present EF status of Ibadan North City, providing important information about the significant contributor influencing the City's overall EF. We specifically focus on energy and food consumption, as they significantly impact the City's environment. The study suggests actionable strategies to decrease the City's EF by analysing these sectors, like promoting renewable energy, supporting local agriculture, and improving public transportation.

Furthermore, the findings strengthen the existing theories that emphasise the significant role of energy infrastructure in influencing the EF in urban areas of developing countries. The study's outcomes can be implemented in real-life situations, particularly in urban planning and energy policy, to underscore the necessity for more dependable and sustainable energy solutions to reduce the EF and promote environmental sustainability effectively.

However, while our study provides valuable insights into the EF of Ibadan North, Nigeria, it is crucial to recognise the limitations imposed by the number of EF components, which may hinder the broader applicability of our findings. In addition, the estimation of the energy footprint was based on reported data, which might not accurately reflect unregulated or informal energy consumption, such as unauthorised connections or unrecorded generator usage. This is despite attempts to ensure anonymity and confidentiality. Moreover, the study might have undervalued the influence of specific food items, especially those not frequently consumed, warranting further investigation to address these lapses.

These assumptions may result in underestimating or misrepresenting the actual EF. Therefore, it is critical to consider limitations when interpreting the findings and drawing conclusions from the study.

As such, it is crucial for future studies to address these gaps and emphasise longitudinal study to incorporate more EF components, such as waste, housing, and transportation, for a more holistic context of the EF of the study area, considering the growing importance of the urban regions in the pursuit of global sustainability.

However, despite these limitations, our study emphasises Nigeria's mega City's environmental sustainability, thus offering evidence-based insight for policy actions to promote sustainable urban consumption practices, mainly promoting a shift to sustainable energy, food production, and consumption that could further minimise ecological impacts.

4. Conclusion

Our study examines Ibadan North, Nigeria's environmental sustainability by exploring its EF. Findings indicate Ibadan North has sustainable consumption, with an EF of 0.43gha/capita. The most significant contribution to this EF comes from energy, which accounts for 0.4gha/capita or 93%. Conversely, the food footprint (0.01gha/capita) contributes less than 3% of the EF share. Our findings can serve as a model for other urban cities in Nigeria, demonstrating the potential of maintaining low EFs while supporting urban development, contributing valuable insights for urban planners and local authorities in developing evidence-based policy initiatives that promote sustainable energy and food consumption practices while addressing the need for sustainable urban development.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data available on request from the corresponding author upon reasonable request.

Author Contribution Statement

Henry Sawyerr: Conceptualization, Methodology, Validation, Formal analysis, Writing - review & editing, Supervision, Funding acquisition. **Edet Otto:** Methodology, Formal analysis, Investigation, Writing - original draft, Funding acquisition. **Micheal Akinyemi:** Investigation, Visualization, Project administration, Funding acquisition.

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