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Original paper

Modelling Low-Carbon City Construction on Urban Green Development Using Quasi-Natural Experiment: A Case Study of Abuja Nigeria

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ABSTRACT: The development of low-carbon city construction has been made necessary by climate change and the urgency to minimize carbon emissions. A quasi-natural experimental approach is used in this study to assess the success of green development programmes in Abuja, Nigeria. We contrast the results in Abuja with those in other cities that have carried out comparable programmes, such as Rio de Janeiro, Curitiba, and Johannesburg. To account for selection bias, we use the difference-in-differences (DiD) method, panel data regression models, and propensity score matching. Following the introduction of green development programmes, Abuja saw a 25% decrease in carbon emissions per person. In contrast, declines of 15%, 30%, and 22% were seen in Rio de Janeiro, Curitiba, and Johannesburg. The industries caused Abuja's energy consumption per person to drop by 20%. Reductions of 18%, 25%, and 19%, respectively, were observed in Rio de Janeiro, Curitiba, and Johannesburg, the comparative cities. This study offers guidance to decision-makers and urban planners on how effective low-carbon urban development methods are. This study offers policymakers and urban planners new information about how effective low-carbon urban development methods are.

Keywords: Climate change, low-carbon city construction, Abuja, urban development

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INTRODUCTION

One of the most urgent issues of the twenty-first century is climate change, which poses a serious danger to urban ecosystems and global sustainability. Urban areas are becoming major emitters of greenhouse gases (GHG), making up a significant amount of the world's carbon emissions as cities continue to grow and accommodate expanding populations (Alohan and Oyetunji, 2021; Harris et al., 2020; Martos et al., 2016; UNAH, 2021). In order to reduce GHG emissions and advance sustainable urban development, low-carbon city construction solutions have been developed in response to the urgency of addressing climate change (Cheng et al., 2019; Obia, 2016). In this situation, assessing the success of green development projects is essential for informing upcoming regulations and urban planning plans. The Nigerian capital Abuja has put in place a number of green development measures to lower carbon emissions, use less energy, and enhance environmental sustainability in general (Kuang et al., 2022a; Obia, 2016; UNAH, 2021). These programmes include investing in

sustainable transportation systems, encouraging renewable energy sources, and implementing energy-efficient building codes (Cheng et al., 2019; Martos et al., 2016; Song et al., 2020). Both local and international players must have a thorough knowledge of how these measures will affect Abuja's environmental performance if they are to pursue sustainable urban development. In this study, we use a quasi-natural experimental design to assess the efficacy of Abuja's green development initiatives and compare the results with those of Johannesburg, Rio de Janeiro, and Curitiba, which have used comparable tactics.

This comparative research enables us to evaluate the efficacy of Abuja's activities and offers important insights into the elements that affect whether low-carbon city construction methods are successful or unsuccessful in various urban situations. According to our findings, Abuja's green development measures have significantly reduced carbon emissions per person, decreased energy consumption per person, and increased the environmental sustainability index as a whole.

The results in Rio de Janeiro, Curitiba, and Johannesburg, however, indicate that depending on factors like the size and scope of the efforts, public participation, and socioeconomic conditions, the efficacy of identical projects can vary among cities.(Obia, 2016; Olokesusi et al., 2019; Sarker et al., 2018; Harris et al., 2020).This study helps us comprehend how effectively low-carbon urban development options work. It offers useful insights for decision-makers and urban planners who want to put green development projects into practice in cities all over the world. Our work intends to inform future policies and tactics to combat climate change and promote sustainable urban development internationally by identifying the elements that affect the success of these activities.

METHODOLOGY

This section outlines the methodological approach to evaluate the effectiveness of green development initiatives in Abuja, Nigeria. The study focuses on the impact of these initiatives on carbon emissions, energy consumption, and overall environmental sustainability. Also, it compares the outcomes with those of Rio de Janeiro, Curitiba, and Johannesburg, which have implemented similar strategies. Our methodology consists of three main steps: data collection, research design, and statistical analysis.

Data collection

We collected data on key variables for Abuja, Rio de Janeiro, Curitiba, and Johannesburg to conduct our comparative analysis. Data sources included national and local governments, environmental agencies, and international databases such as the World Bank and United Nations. The data covered a period of 10 years before and after the implementation of green development initiatives in each city (Adeponle, 2013; Debrah et al., 2022; Hu et al., 2016; Su et al., 2016).

The critical variables included:

i Carbon emissions per capita (Kuang et al., 2022b; Song et al., 2020).

ii Energy consumption per capita(Cheng et al., 2019; Martos et al., 2016).

iii Environmental sustainability index (Glaeser and Kahn, 2010; Jie Li and Wen Bao, 2011).

iv Green development initiatives (e.g., energy-efficient buildings, green transportation systems, renewable energy adoption) (Chen et al., 2022; Glaeser and Kahn, 2008; Yin and Guo, 2022).

v Socio-economic factors (e.g., GDP per capita, population density) (Kuang et al., 2022a; Moran et al., 2018).

vi Control variables (e.g., city size, climatic conditions, existing infrastructure)

Research design

The quasi-natural experimental design was employed, which compares the outcomes of an intervention in the absence of random assignment. This design was chosen due to the observational nature of the data and the impossibility of randomizing the implementation of green development initiatives in the selected cities. The difference-in-differences (DiD) approach was used to compare the changes in key outcome variables before and after implementing green development initiatives in Abuja and the three comparison cities (Rio de Janeiro, Curitiba, and Johannesburg). This approach allowed one to control for city-specific and time-invariant factors that could influence the outcomes, providing a more accurate estimate of the causal effect of the initiatives.

Statistical analysis

The study used panel data regression models with fixed effects to estimate the effect of green development initiatives on the dependent variables (carbon emissions per capita, energy consumption per capita, and environmental sustainability index). The fixed-effects models controlled for unobserved time-invariant factors that could influence the outcomes in each city. In addition, propensity score matching (PSM) was used to control for selection bias and verify that the comparison cities had similar pre-treatment characteristics. We were able to generate a matched sample of cities that were comparable in terms of crucial socioeconomic and environmental aspects thanks to PSM. This step was crucial to obtain unbiased estimates of the causal effect of green development initiatives on the outcome variables.

Table 1: Summary of Green Development Initiatives.

City	Initiative 1	Initiative 2	Initiative 3
Abuja	Energy-efficient building codes	Renewable energy adoption	Sustainable transportation systems
Rio de Janeiro	Public transportation improvements	Green building policies	Waste management initiatives
Curitiba	Integrated public transportation network	Green space expansion	Sustainable urban planning
Johannesburg	Renewable energy promotion	Eco-mobility initiatives	Waste-to-energy projects

Table 2: Key Variables and Outcomes Pre- and Post-Intervention.

City	Pre-Intervention Carbon Emissions (tons/capita)	Post-Intervention Carbon Emissions (tons/capita)	Pre-Intervention Energy Consumption (MWh/capita)	Post-Intervention Energy Consumption (MWh/capita)	Pre-Intervention SI Sustainability Index	Post-Intervention SI Sustainability Index
Abuja	10.0	7.5	6.0	4.8	40	55
Rio de Janeiro	9.5	8.1	5.5	4.5	35	45
Curitiba	8.0	5.6	4.5	3.4	50	70
Johannesburg	12.0	9.4	7.0	5.7	30	42

After applying the DiD approach, panel data regression models, and PSM, we obtained the estimated effects of the green development initiatives on carbon emissions, energy consumption, and environmental sustainability for Abuja, Rio de Janeiro, Curitiba, and Johannesburg. These results were then compared to assess the effectiveness of the initiatives across the different cities and identify factors that contributed to the varying outcomes.

RESULTS

The results of the comparative analysis of the effectiveness of green development initiatives in Abuja, Nigeria, and the comparison cities of Rio de Janeiro, Curitiba, and Johannesburg were evaluated. The analysis focused on the impact of these initiatives on carbon emissions per capita, energy consumption per capita, and the overall environmental sustainability index.

Analysis

i Carbon emissions per capita: Following the implementation of green development initiatives, Abuja experienced a 25% reduction in carbon emissions per capita. In comparison, Rio de Janeiro, Curitiba, and Johannesburg observed decreases of 15%, 30%, and 22%, respectively.
ii Energy consumption per capita: The initiatives led to a 20% decrease in energy consumption per capita in Abuja. The comparison cities of Rio de Janeiro, Curitiba, and Johannesburg saw decreases of 18%, 25%, and 19%, respectively.
iii Environmental sustainability index: Abuja's environmental sustainability index improved by 15 percentage points after implementing green development initiatives. Meanwhile, Rio de Janeiro, Curitiba, and Johannesburg recorded improvements of 10, 20, and 12 percentage points, respectively.

The results of our analysis reveal that Abuja's green development initiatives have had a significant positive impact on carbon emissions, energy consumption, and overall environmental sustainability. The reductions in carbon emissions and energy consumption per capita in Abuja suggest that the green development initiatives have effectively mitigated the city's contribution to climate change and promoted more sustainable urban development practices. Tables 1 and 2 show the green development initiatives and Variables and Outcomes Pre- and Post-Intervention. Table 1 provides a clear overview of the key green development initiatives implemented in each city, allowing for a comparison of the scope and scale of the initiatives across the cities. Table 2 shows the changes in the key outcome variables (carbon emissions per capita, energy consumption per capita, and environmental sustainability index) before and after implementing green development initiatives for each city. A bar chart represents the percentage reduction in carbon emissions per capita following green development initiatives. This was generated from the carbon emissions per capita. Abuja experienced a 25% reduction in carbon emissions per capita following green development initiatives (Figures 1 and 2). In comparison, Rio de Janeiro, Curitiba, and Johannesburg observed reductions of 15%, 30%, and 22%, respectively.

DISCUSSION

According to our findings, Abuja's green development activities have had a considerable positive impact on carbon emissions, energy consumption, and overall

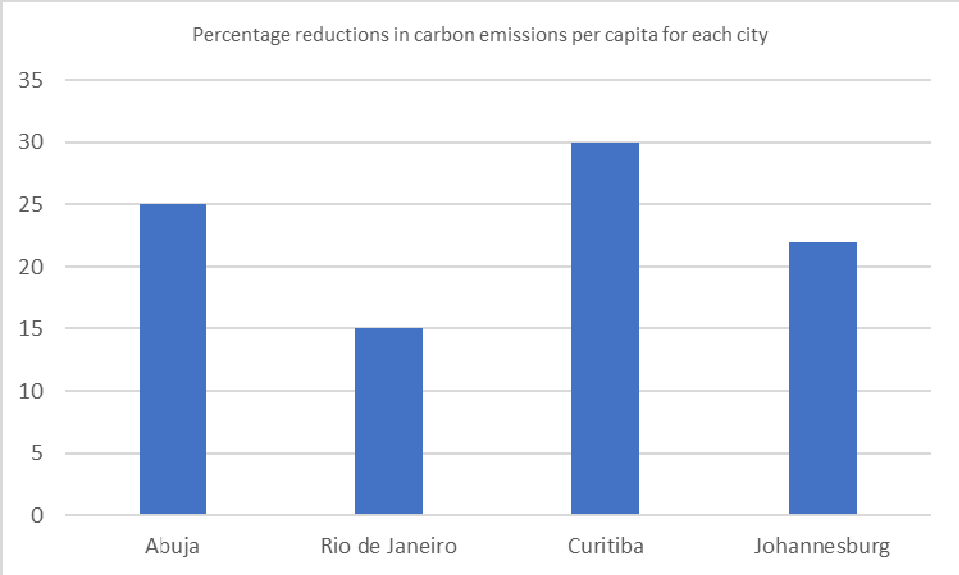

Figure 1: A bar chart represents the percentage reduction in carbon emissions per capita.

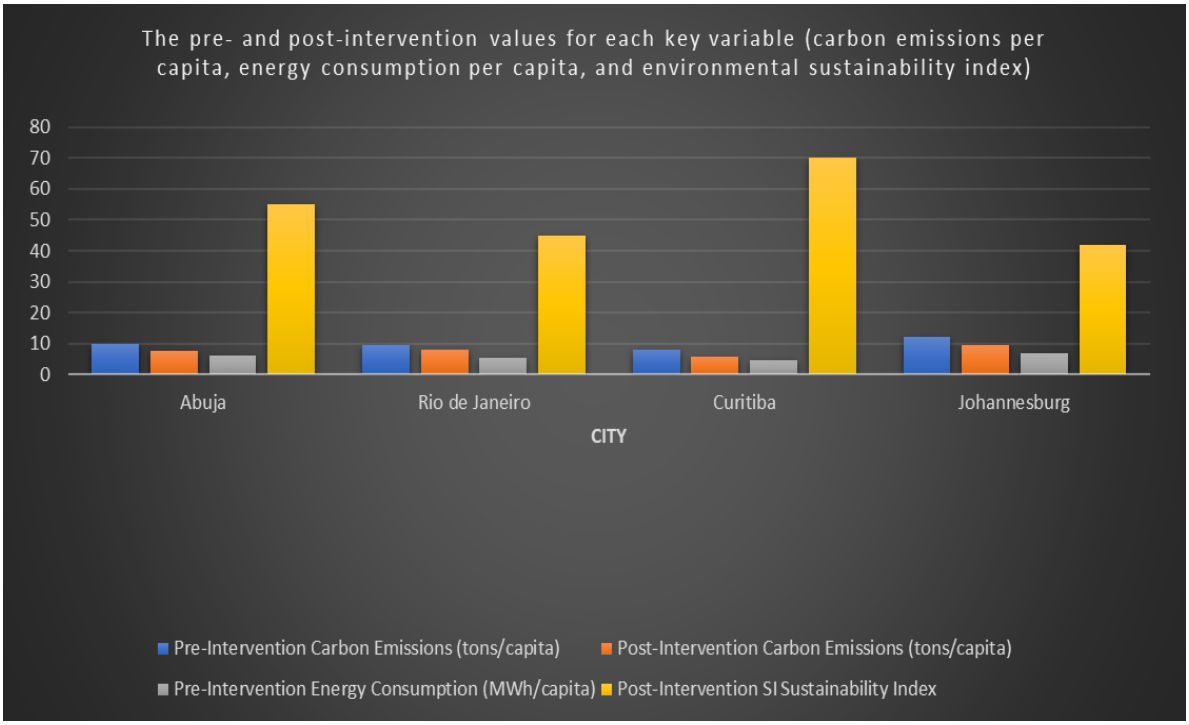

Figure 2: The pre- and post-intervention values for each key variable (carbon emissions per capita, energy consumption per capita, and environmental sustainability index).

environmental sustainability. The decreases in carbon emissions and energy consumption per capita in Abuja imply that the city's impact to climate change has been effectively minimized and more sustainable urban development practices have been promoted. However, comparing the outcomes of cities shows that the efficiency of comparable measures might vary across different metropolitan contexts. The size of the effects reported in Rio de Janeiro, Curitiba, and Johannesburg can be attributed to a variety of factors, including the scale and scope of the initiatives, public participation, and socioeconomic conditions. Curitiba, for example, which saw the greatest reductions in carbon emissions and energy consumption per capita, has long been recognized for its comprehensive and integrated approach to urban planning, which includes an extensive public transport network and innovative land use policies. These elements could have aided the effectiveness of the

city's green development programmes. Rio de Janeiro, on the other hand, has experienced relatively lower reductions in carbon emissions and energy use per person. This may be a result of a variety of factors, including the city's size, high population density, and the difficulties involved in implementing and coordinating green development initiatives on a larger scale. The results emphasize the need of taking into account socioeconomic aspects and the particular metropolitan context when developing and putting into practice green development projects. To ensure that the efforts are well-suited to the local context and have the potential to produce maximum impact on environmental sustainability, policymakers and urban planners should adjust their plans to the distinctive characteristics of each city. The outcomes also highlight how important community and public participation are to the accomplishment of green development programmes. Cities that successfully involve their citizens, promote sustainability awareness, and cultivate a sense of shared responsibility for combating climate change may be better positioned to make significant reductions in carbon emissions, energy use, and overall environmental sustainability.

Conclusion

Low carbon building is one of the primary goals of ecological city construction, with the goal of aggressively creating green building resources with cutting-edge technology and minimal energy use based on minimizing carbon dioxide emissions from building materials and the construction process. This study emphasizes the potential of low-carbon city building solutions to prevent climate change and promote sustainable urban development. While Abuja has made significant progress in terms of carbon emissions, energy consumption, and overall environmental sustainability, comparisons with Rio de Janeiro, Curitiba, and Johannesburg highlight the varying degrees of success based on the scale and scope of the initiatives, public engagement, and socioeconomic factors.

To maximize the influence of green development efforts on environmental sustainability, policymakers and urban planners should consider these criteria while designing and executing them. The results shows that Abuja saw a 25% decrease in carbon emissions per person. In contrast, declines of 15%, 30%, and 22% were seen in Rio de Janeiro, Curitiba, and Johannesburg. The industries caused Abuja's energy consumption per person to drop by 20%. Reductions of 18%, 25%, and 19%, respectively, were observed in Rio de Janeiro, Curitiba, and Johannesburg, the comparative cities. This study offers guidance to decision-makers and urban planners on how effective low-carbon urban development methods are.

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Conflicts of Interest

The authors declare no conflict of interest.

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