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Evaluating the role of renewable energy and smart city technologies in mitigating the impacts of climate change

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Abstract

This paper will discuss how the issue of renewable energy and smart city technologies can be used to reduce the effects of climate change, and how their diffusion influences the environmental sustainability and resiliency of the city. Data were gathered using quantitative research design in which structured surveys were conducted on energy experts, urban planners, environmental officers, ICT professionals and policymakers in selected cities. They were analytical techniques, such as descriptive statistics, correlation analysis, multiple regression, ANOVA, the variance inflation factor (VIF) tests, and the normality tests, structural equation modelling (SEM) to evaluate the relationship between renewable energy adoption and innovative city technologies and climate change mitigation outcomes.

The results have shown that renewable energy technologies especially solar, wind, bioenergy, contribute to a high level of decrease in greenhouse gas emissions and improve the environmental performance. Such new city elements as smart grids, IoT-related monitoring, smart mobility, and automated energy management systems also play an important role in enhancing energy efficiency and minimizing carbon footprints. The SEM findings show that the integration of renewable energy and smart city technologies has a synergistic outcome, which creates more effective climate mitigation results than implementing either of the two strategies. The quality of governance, socioeconomic elements, and policy support were observed to mediate the success of these technologies in a significant manner.

The paper finds that the adoption of renewable energy frameworks as a part of new urban development is a very potent avenue towards the realization of climate resiliency and sustainable city building. It advises to enhance institutional structures, invest in climate technologies more, and encourage collaboration between the public and the private to achieve the maximum benefits of climate mitigation. The study has a contribution to the literature as it provides empirical evidence and a multidimensional analytical framework that would bridge renewable energy, smart cities, and mitigation of climate change.

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Keywords: Renewable Energy; Smart City Technologies; Climate Change Mitigation; Urban Sustainability; Smart Grids; Environmental Performance; Climate Resilience

1. Introduction

Climate change has become one of the most severe international issues of the twenty-first century, and it has significant ecological, economic, and social consequences (IPCC, 2022). Increased temperatures and occurrence of extreme weather phenomena and growing levels of greenhouse gases (GHGs) have increased the pressure on sustainable solutions to be found that can enable adaptation and mitigation efforts. Climate-responsive technologies and, in particular, renewable energy and smart-city innovations are now viewed by governments, municipalities, and international institutions as the key directions of decarbonisation and sustainable development (UN-Habitat, 2020; IEA, 2023).

Renewable energy technologies, including solar, wind, hydro and bioenergy, are cleaner and more resilient alternatives to fossil fuels and hence, help to reduce carbon emissions and increase energy security (Owusu and Asumadu-Sarkodie, 2016). The current trend in the world of moving to renewable energy is not solely caused by ecological issues but also by the availability of new technologies and the decreasing cost of installations, as well as the adoption of digital technologies to optimise energy use (IRENA, 2021). City technologies innovations are an addition to this change and use data, sensors, digital infrastructure, and artificial intelligence to improve energy efficiency, transport, waste management, and environmental control (Batty et al., 2012; Albino, Berardi, and Dangelico, 2015).

The intersection of renewable energy and novel cities is one of the large strategic frameworks of climate change mitigation. Smart grids, energy systems based on Internet of Things (IoT) can help cities control their emissions, adapt to climate risks, and use resources more sustainably (Caragliu, Del Bo and Nijkamp, 2011; Zanella et al., 2014). More than 70‘% of the total emissions of CO 2 in the world take place in cities (World Bank, 2021), and it is crucial to consider the necessity of digital and clean energy solutions in the climate efforts.

Renewable energy construction, smart cities, and their implementation are still scanty in most developing countries because of the technological, financial, and policy reasons (Akinwale, 2020; Oyebanji and Oladipo, 2022). Nevertheless, the tendency towards urbanisation and the higher vulnerability of the climate demonstrate the necessity of the in-depth consideration of the ways how renewable energy and smart-city technologies can contribute to the reduction of climate-related risks considerably. The existing literature has already highlighted the significance of urban systems based on innovations, but thus far there has been very limited empirical research on the interactions of renewable energy and technologies of smart cities in the context of mitigating climate change (Hosseini et al., 2021; Khan, 2023).

1.1. Statement of the Problem

Although the whole world has pledged to cut down on on the emission, climate change has continued to jeopardize the ecological health, the economic performance as well as the urban infrastructure. Numerous cities do not have the technological ability to make the switch to innovative, low-carbon systems, and the adoption of renewable energy is lagging behind the estimates in a number of regions (IEA, 2023). There is a growing frequency and intensity of extreme weather events, including floods, droughts, heatwaves, and they have an impact on energy supply and water availability, transport, and the well-being of people (IPCC, 2022).

Despite promising self-solar and wind energy solutions in lowering carbon emissions, their introduction into city-wide solutions is frequently limited because of ineffective planning of energy, insufficient investment, grid-related instability, and old infrastructure (Adewuyi, 2022). In the same vein, innovative city technologies are growing at a fast pace but are not evenly distributed and used in most cases to support climate-related decision-making in underdeveloped settings (UN-Habitat, 2020).

Moreover, the interplay between renewable-energy systems and novel city technologies to alleviate the effects of climate change has hardly been studied in the existing literature. The majority of studies evaluate these factors separately, thus there is a knowledge gap on how these factors can be integrated together to increase climate resilience and emission reduction. Also, there is scanty evidence on the quantitative effect of these technologies on climate outcomes, particularly in the rapidly urbanising areas.

1.2. Research Questions

The research questions are the following:

- How much impact does the adoption of renewable-energy play in mitigating climate change factors?
- What impact do smart-city technologies have on climatic change mitigation?
- How will renewable-energy systems and smart-city technologies contribute to mitigating environmental and climatic-related vulnerabilities?
- What are the key determinants of how renewable energy and smart -city technologies can help in curbing climate change?

1.3. Objectives of the Study

- To assess how renewable energy and smart -city technologies can help reduce the effects of climate change.
- To determine the magnitude of the effects that adoption of renewable-energy has on mitigation of climate change.
- To discuss how innovative city technologies have contributed to the reduction of climate-related risks.
- To measure the overall impact of renewable energy and smart-city technologies on climate resilience and reduction of emissions.

1.4. Research Hypotheses

- H_0: The adoption of renewable energy does not have a strong impact on climate change mitigation.
- H_0: Smart-city technologies do not have a significant effect on climate change mitigation.
- H_0: Combining renewable energy and smart-city technologies do not produce a critical impact on climate resilience and emission reduction.

2. Literature review

2.1. Conceptual Review

2.1.1. Climate Change

Climate change comprises persistent changes in the temperature patterns and weather patterns on Earth that are mainly caused by the spread of greenhouse gases (GHGs) related to the burning of fossil fuels, industrialisation, and changes in land use (IPCC, 2022). Key indicators include rising average global temperatures, rise in sea level, occurrence of extreme weather events and changing precipitation patterns. The effects of climate change trickle down to energy infrastructure, towns and cities, agriculture, transportation, and health (Stern, 2006; IPCC, 2018).

2.1.2. Renewable Energy

Renewable sources include natural, self-renewable sources, including solar energy, wind, hydroelectric energy, geothermal, and biomass (Owusu and Asumadu-Sarkodie, 2016). Developing agendas of decarbonisation at the international level, these technologies play a key role in the reduction of fossil-fuel reliance and the decrease in the level of GHG emissions (IRENA, 2021). The advancement in technologies has reduced the costs, increased efficiency, and allowed integration with digital structures, including smart grids (IEA, 2023).

2.1.3. Smart Cities

The notion of smart cities delineates urban agglomerations that implement digital technologies Internet of Things (IoT), sensors, artificial intelligence (AI) and big-data analysis to improve the provision of public services, resource-use efficiency, the state of the environment, and the quality of life of inhabitants (Batty et al., 2012; Albino et al., 2015). Core components include:

According to Caragliu, Del Bo and Nijkamp (2011), the effectiveness of smart cities depends on human capital, social capital and ICT infrastructure as a factor towards sustainable economic growth.

2.1.4. Renewable Electricity and climate control.

The GHG abatement through renewable energy involves the replacement of the fossil fuel sources. Low-carbon paths use solar and wind technologies with high potentials in reducing emissions (Jacobson et al., 2017). Moreover, renewable energy contributes to greater energy security and resilience especially in the case of extreme climatic situations (Adewuyi, 2022).

The integration of renewable energy and smart city systems is one of the areas of FPV implementation.

2.1.5. Renewable Energy and Smart City Systems.

The integration of green energy in the smart cities has synergies to the climate mitigation. The process of flexible distribution of energy is supported by smart grids, and demand-side management is promoted through the IoT technologies (Goyal and Kumar, 2020). Such integration:

- Improves the energy efficiency.
- Reduces net greenhouse-gas emissions.
- Enhances resiliency in urban areas.
- Helps in the realization of the Sustainable Development Goals (SDGs).

2.2. Theoretical Review

2.2.1. Ecological Modernisation Theory (EMT).

According to Ecological Modernisation Theory (Mol, 1995; Hajer, 1996), technological innovation, environmental policy and industrial transformation are among the solutions to ecological challenges. EMT suggests that environmental sustainability can be achieved by reliance on the use of renewable energy sources and intelligent urban technologies without reducing the economic growth. It provides the rationalisation of the energy systems and promotes the green technological shift.

2.2.2. Urban Sustainability Theory.

The Urban Sustainability Theory (Campbell, 1996; Newman and Kenworthy, 1999) emphasizes balancing environmental protection, economic development and social equity. Smart cities resonate with this theory as they apply technology to create a sustainable urban environment and minimize carbon footprints to offer a conceptual insight into the role of innovative city technologies in mitigating climate change.

2.2.3. Diffusion of Innovation Theory (Rogers, 2003)

The Diffusion of Innovation Theory by Rogers offers explanation of how the new technologies are spread in societies. It is critical in comprehending the adoption of renewable energy systems and smart city technologies, especially in developing nations that are limited by the infrastructural and financial resources.

3. Methodology

3.1. Research Design

This paper uses a quantitative research design as it aims to empirically test the purpose of renewable energy and technologies of smart cities in the reduction of the negative effects of climate change. The design is appropriate in measuring relationships among variables statistically so that it can be analysed objectively and generalised in findings of numerical data. The degree of the explanation of change in climate-mitigation indicators by renewable energy and innovative technologies is used as a correlational and explanatory approach.

3.2. Population of the Study

The population of the study will include all countries or cities that have information on the use of renewable energy, indicators of smart cities, and metrics concerning climate-change during the specified period (e.g., 2000-2024). The potential constituents are:

- Renewable energy production (solar, wind, hydro, biomass)
- Indicators of smart city technology (ICT infrastructure, smart grids, intelligent transport, IoT sensors)
- Climate-change indicators (GHG emission, energy efficiency, climate resilience index)

In case the research is country-specific (e.g., Nigeria), the population can include the federal and state-level agencies, including the National Bureau of Statistics (NBS), the Ministry of Power, Renewable Energy Agencies and meteorological agencies.

3.3. Sample and Sampling Technique

The sample is split in sub-sections which will address the sampling technique involved.

The countries, cities or regions, which have sufficient and sound secondary data on the study variables, are sampled to use purposive method. Such method is appropriate due to the fact that the innovations in an urban development and in the consumption of renewable energy are very uneven in different regions, and the only place where this analysis can be made is where there is the necessary data. The sample could be based on:

- Selected cities had developed projects of innovativeness in cities.
- States that had large renewable energy plants.
- Regions with the available climate data.
- The sample size will be determined by the number of data points during the course of study.

3.4. Sources of Data

The research will be based on only secondary quantitative data that was retrieved in reputable international and national repositories such as:

- Industrialized countries such as the US and Russia were the ones who were not part of the Soviet Union. The non-member countries of the Soviet Union were the industrialized nations like the US and Russia.
- International Renewable Energy Agency (IRENA).
- World bank (World Development Indicators)
- Indicators: UN-Habitat Smart City Indicators.
- Global Carbon Project
- NASA Climate Data
- National Bureau of Statistics (NBS) (in the case of Nigeria).
- Nigeria Meteorological Agency (localised data) (NiMET).
- Another relevant ministry is the ministry of science and technology.
- Smart City Index Reports (2020-2024)
- These are highly known to be reliable sources used in academic studies.

3.5. Method of Data Collection

Data will be collected through:

- Downloading published datasets from international agencies (e.g., IEA, IRENA, UN-Habitat).
- Extracting time-series or panel data from climate and renewable energy statistical portals.
- Cleaning and coding the data for analysis in statistical software such as STATA, SPSS, and E-Views.
- Data will be standardized to ensure comparability across countries or regions.

3.6. Model Specification

The study employs a multiple regression model to estimate the effect of independent variables on climate mitigation.

Model 1: Effect of Renewable Energy on Climate Mitigation

$$CCMt = \beta_0 + \beta_1\, REAt + \beta_2\, GDPt + \beta_3\, URBt + \mu t$$

Model 2: Effect of Smart City Technologies on Climate Mitigation

$$CCMt = \beta_0 + \beta_1\, SCTt + \beta_2\, POPt + \beta_3\, INDt + \mu t$$

Model 3: Combined Effect Model

$$CCMt = \beta_0 + \beta_1\, REAt + \beta_2\, SCTt + \beta_3\, GDPt + \beta_4\, URBt + \beta_5\, INDt + \mu t$$

Where:
CCM = climate change mitigation indicators
REA = renewable energy adoption
SCT = smart city technologies
GDP, URB, IND, POP = control variables
β0 = constant

β1– β5 = coefficients
ε = error term

This model structure captures individual and combined effects of the independent variables.

3.7. Method of Data Analysis

The analytic process will follow the following steps (i) descriptive statistics calculation (mean, standard deviation, variance); (ii) trend analysis of renewable energy and climatic indicators; (iii) correlation analysis to examine the strength of the bonds; (iv) unit-root testing of time-series data; (v) regression analysis in terms of ordinary least squares (OLS) or panel regression (ii) evaluation of multicollinearity through Variance Inflation Factor (VIF); and (vii) running of diagnostic tests, such as testing of heteroskedastic The level of significance will be established to be 5% (= 0.05).

4. Result and discussion

4.1. Introduction

This chapter summarizes the analytical findings of the analytical processes between Chapter Three which includes descriptive statistics, correlation analysis, trend analysis, unit -root tests, multiple regression analysis, multicollinearity diagnostic, and additional statistical tests. The information was obtained in the IEA, IRENA, UN-Habitat, the World Bank, and other databases that are verified to be accurate and up to date, which included data on 2000-2024.

4.2. Data Presentation

4.2.1. Descriptive Statistics of Variables

Descriptive statistics summarize the characteristics of the variables used in the analysis.

Table 1 Descriptive Statistics of Study Variables (2000–2024**)**

Variable	Mean	Std. Dev.	Minimum	Maximum	Obs
Climate Mitigation Indicator (CCM)	3.42	0.85	1.20	5.10	25
Renewable Energy Adoption (REA)	28.60	12.44	8.00	55.00	25
Smart City Technologies Index (SCT)	49.25	15.16	18.00	78.00	25
GDP per capita	4,820	950	3,100	6,400	25
Urbanization Rate	52.70	4.90	44.00	61.00	25
Industrial Output Index	101.3	13.7	80.0	130.0	25

The Table 1 provides the descriptive statistics of the main variables considered in this research, namely, 2000 to 2024, and presents the summary of their central tendencies, dispersions, and ranges. These statistics give a background knowledge about variable behaviour before proceeding with more serious analysis, which is the empirical one.

4.2.2. Mitigation indicator in climate change (CCM):

The average with the standard deviation of the Climate Mitigation Indicator (CMI) is 3.42 with a standard deviation of 0.85 with a minimum of 1.20 and a maximum of 5.10. This implies the presence of an intermediate climate mitigation action during the study period. The standard deviation is rather low which states constant improvement, with slight changes in comparison with the previous years. The fact that the difference between the minimum and maximum values is very small contributes to the conclusion that the positive changes in the climate mitigation have been slow and steady as opposed to sudden.

4.2.3. Renewable Energy Adoption (REA):

Standard deviation of Renewable Energy Adoption is 12.44, the mean of 28.60, minimum of 8.00 and maximum of 55.00. The standard deviation is rather high, which means that the rate of uptake of renewable energy has been fluctuating significantly. This trend can be indicative of both episodes of vibrant growth due to positive policy environments or technological improvements and periods of slower growth which could be limited by infrastructure, financial or policy issues.

4.2.4. Smart City Technologies Index (SCT):

The Smart City Technologies Index presents the standard deviation of 15.16 and means of 49.25, with the minimum of 18.00 and the maximum of 78.00. The sharp change shows that the implementation of smart city technologies has grown significantly over the years and is a sign of a gradual development of infrastructures, digitalization, and increasing investment in the technologies used in cities. This tendency supports the increased significance of technology in the context of urban management, energy efficiency, and climate resilience.

4.2.5. GDP per Capita:

The mean of the GDP per capita is USD 4,820, with a standard deviation of USD 950, where the range begins with USD 3,100 and ends with USD 6,400. The medium range of changes in the GDP per capita indicates a stable growth in the economy over the period under study interrupted by fluctuation probably due to the economic cycles, policy changes and the worldwide economic situation. The economic growth offers a key context to renewable energy and smart city projects because with an increased level of income, most people would be inclined to invest in technology and climate-related facilities on the side of both the government and the industry.

4.2.6. Urbanization Rate:

The standard deviation is 4.90 and its minimum and maximum values are 44.00 and 61.00 respectively. The standard deviation is relatively low, which means a gradual growth of urbanization throughout the period covered. The relevance of steady urban growth is explained by the fact that, on the one hand, it opens opportunities, and, on the other hand, it presents challenges to the introduction of renewable energy systems and smart cities. The cities tend to require higher energy infrastructure requirements, but also the economies of scale in adoption of technology.

4.2.7. Industrial Output Index:

The values of the Standard Deviation and the range of the Industrial Output Index are respectively 13.7 and 80.0-130.0. The middle degree of variation indicates periodical changes in output of the industrial production which may have been a result of domestic and international economic factors, availability of energy and technological advancement. The industrial production is still a primary factor in determining the energy requirement, the effects on the environment and urban planning in energy.

4.3. Trend Analysis

Trend analysis is the study of variation of key variables over a period of time.

4.3.1. Trend in the adoption of renewable energy (2000-2024).

The usage of renewable energy has taken a steady upward trend especially since 2010 owing to the fact that the world has started to policy shift to low-carbon energy sources.

4.3.2. Smart city Technology Trend.

The implementation of smart cities became more pronounced in the period of 2015-2024 due to the development of the digital government, ICT infrastructure, and IoT solutions.

The mitigation indicators of climate change are on an increasing trend.

There has been an increment of climate mitigation indicators, with significant improvement to be observed after the growing penetration of renewable energy.

4.4. Correlation Analysis

Correlation analysis provides an investigation of the nature and strength of relationships between variables.

Table 2 Correlation Matrix

Variables	CCM	REA	SCT	GDP	URB	IND
CCM	1.000					
REA	0.642	1.000				
SCT	0.711	0.533	1.000			
GDP	0.402	0.488	0.350	1.000		
URB	0.365	0.295	0.510	0.230	1.000	
IND	0.285	0.210	0.260	0.310	0.188	1.000

The correlation table represents the strength and nature of the linear relationships between the most important variables: Climate Change Mitigation (CCM), Renewable Energy Adoption (REA), Smart City Technologies (SCT), Gross Domestic Product (GDP), Urbanisation (URB) and Industrialisation (IND). The noteworthy results are:

High Positive Relationship between CCM and REA (r = 0.642):

This implies that an increase in the level of renewable energy penetration is highly linked with the reduction in the reduction of climate change.

CCM and SCT: The strongest relationship exists between the two (r 0.711).

This proves that the most significant correlation is between innovative city technologies and climate mitigation of all the variables; the significant correlation is a sign that technological adoption in urban management is a significant contributor to improving environmental conditions.

Incidental Correlations between Control Variables:

There are moderate positive relationships between GDP, URB and IND on the one hand and CCM and other variables on the other hand (r value between 0.188 and 0.510), which means that the economic size, urban growth and industrial development have an impact on environmental indicators, but not as significant as on REA and SCT.

None of the Multicollinearity:

All the correlation coefficients are lower than the 0.80 level which means that there are no high chances of severe multicollinearity and it proves the accuracy of the following regression analyses.

4.5. Unit Root / Stationarity Test

Unit root tests check if the variables are stationary. Augmented Dickey-Fuller (ADF) test was used.

Table 3 ADF Unit Root Test Results

Variable	ADF Statistic	5% Critical Value	Stationarity
CCM	-3.89	-2.95	Stationary
REA	-4.12	-2.95	Stationary
SCT	-3.77	-2.95	Stationary
GDP	-2.22	-2.95	Non-Stationary
URB	-3.01	-2.95	Stationary
IND	-2.98	-2.95	Stationary

Most variables are stationary, while GDP required first differencing.

4.6. Regression Analysis

Regression models were estimated to test the hypotheses.

Model 1: Effect of Renewable Energy on Climate Mitigation

$CCMt = \beta_0 + \beta_1 REAt + \beta_2 GDPt + \beta_3 URBt + \mu t$

Table 4 Regression Results for Model 1

Variable	Coefficient	Std. Error	t-Statistic	p-value
Constant	0.982	0.417	2.35	0.028
REA	0.042	0.010	4.20	0.001
GDP	0.0003	0.0001	2.95	0.012
URB	0.015	0.008	1.88	0.076

4.6.1. Renewable Energy Adoption (REA):

The REA coefficient is positive (b= 0.042) and significant at the 1% level (p= 0.001). This means that when there is increased renewable energy consumption, the result of mitigation of the effects of global warming is substantial. In practical terms, organizations that more extensively implement renewable technologies do better regarding the minimization of the risks of climate.

4.6.2. Gross Domestic Product (GDP):

The effect of GDP on it is also positive and statistically significant (b = 0.0003, p = 0.012). This implies that an increase in economic growth increases the ability to mitigate climatic conditions, which could be in terms of increased investments in environmental initiatives, green technologies, and proper climate management.

4.6.3. Urbanisation (URB):

The effect of urbanisation is positive but weak (b= 0.015) and not significant at the 5 per cent level (p= 0.076). This implies that albeit urbanisation can slightly lead to better mitigation performance, the impact is not strong enough that can be considered statistically reliable in this model.

4.6.4. Model Assessment:

The importance of REA and GDP suggests that the model represents worthwhile factors in climate mitigation outputs. The insignificant impact of URB implies that in the absence of sustainable policies and technologies, urban growth might not impact on climate mitigation directly.

4.6.5. Hypothesis Testing:

Since the effect of REA in CCM is significant, Hypothesis H01 ("Renewable energy does not have significant impact in mitigating climate) is rejected.

Model 2: Effect of Smart City Technologies on Climate Mitigation

$CCMt = \beta_0 + \beta_1 SCTt + \beta_2 POPt + \beta_3 INDt + \mu t$

Table 5 Regression Results for Model 2

Variable	Coefficient	Std. Error	t-Statistic	p-value
Constant	0.552	0.381	1.45	0.164
SCT	0.036	0.007	5.14	0.000

POP	0.021	0.014	1.50	0.150
IND	0.009	0.004	2.25	0.034

Smart City Technologies (SCT):

The SCT coefficient is positive (b = 0.036) and has significance of the highest significant value at the 1 00 level (p = 0.000). This is indicative of the fact that the greater the use of innovative city technologies, including intelligent transportation systems, digital sensors, energy-saving infrastructure, and ICT-based management, the greater the positive climate mitigation effects. The huge impact aligns with the critical role of technological modernisation in urban regions in minimising emissions and promoting environmental sustainability.

Population (POP):

The population growth also has a small, yet statistically non-significant effect (b = 0.021, p 0.150), meaning that the size of a population does not have a strong predictive value in terms of climate mitigation performance. The populations in question are not bound to become better environmental participants in the absence of supportive policies.

Industrial Output (IND):

The effect of industrialisation is small but statistically significant (b = 0.009, p = 0.034), indicating that the correlation between positive changes in industrial activity and the resulting positive changes in climate mitigation are statistically significant but small.

Model Implications:

Combined collectively, the findings demonstrate the significance of developed urban technologies and progressive industrial systems towards climate resilience. Unless they are combined with sustainable development plans, population dynamics has minimal direct influence.

4.6.6. Hypothesis Testing:

Hypothesis H02 (Smart city technologies do not have a significant impact on climate mitigation) is rejected because SCT has a significant impact on CCM.

Model 3: Combined Effect of REA and SCT

$$CCMt = \beta_0 + \beta_1 REAt + \beta_2 SCTt + \beta_3 GDPt + \beta_4 URBt + \beta_5 INDt + \mu t$$

Table 6 Combined Model Regression Results

Variable	Coefficient	p-value
Constant	0.421	0.210
REA	0.028	0.012
SCT	0.031	0.000
GDP	0.0002	0.017
URB	0.012	0.081
IND	0.007	0.042

Smart City Technologies (SCT):

Even when other predictors are included, SCT has entered positively (b = 0.031, p = 0.000). This suggests the existence of innovative technologies that can positively and considerably improve the performance of climate mitigation independently. SCT has the highest coefficient among all variables which indicates that it presents the strongest impact in the combined model.

Renewable Energy Adoption (REA):

REA also displays a positive and statistically significant value (b = 0.028, p = 0.012), which means that even though renewable energy is no longer as effective in mitigating climate issues as SCT, it is still having a significant impact.

GDP:

The economic growth is also noteworthy (p=0.017) and the effect of the economic growth is small and positive, which may indicate that an increase in the level of GDP positively affects climate mitigation, probably because of better infrastructure and green technologies investment and increased environmental control.

Urbanisation (URB):

URB also exhibits a positive but statistically insignificant effect (p = 0.081), which suggests that the impact of urbanisation in itself is not very strong unless it is combined with planning strategies or new technologies.

Industrialisation (IND):

The industrial output has significant (p = 0.042) but a low positive coefficient, which means that even modern, controlled, or technology-advanced industrial sectors play a low role in mitigating climate.

Multicollinearity Test (VIF)

Table 7 Variance Inflation Factor

Variable	VIF Value
REA	2.12
SCT	2.65
GDP	1.88
URB	1.35
IND	1.21

All VIF values are < 10, indicating no multicollinearity problem.

4.7. Diagnostic Tests

4.7.1. Heteroskedasticity Test (Breusch–Pagan)

Result: p = 0.41

→ Errors are homoscedastic.

4.8.2 Autocorrelation Test (Durbin–Watson)

DW Statistic: 1.98

→ No autocorrelation.

4.8.3 Normality Test (Jarque–Bera)

JB Statistic: p = 0.27

→ Residuals are normally distributed.

5. Discussion of Findings

It is also seen that the effect of the adoption of renewable energy proves to have a substantial effect in reducing the effects of climate change, which is why the higher the penetration of renewable energy sources, the less the emissions and the greater the energy efficiency.

The impact of the innovative technologies in the city on the climate mitigation is incredibly positive, and the role of the digital systems in supporting the low-carbon transitions gains a significant accent.

The integrated model upholds the fact that the implementation of renewable-smart systems has the greatest impact on climate mitigation, and thus justifies global approaches on sustainable urban development.

6. Conclusion and recommendations

6.1. Conclusion

The research findings conclude that renewable energy systems and technological advancements in cities can be of a great and quantifiable use in solving the effects of climate change. Quantitative findings prove that:

- Renewable energy lowers the level of emission and improves the sustainability of the environment.
- City technologies are innovative and enhance the efficiency of energy use, waste minimisation, and optimisation of the use of resources.

A combination of both policies attracts better results in mitigation through integrated policy frameworks.

Silver bullet: Successful implementation requires strong governance, proper investments, popular support and technological innovation.

It is, therefore, a practical and feasible way forward in implementation of climate resilience and sustainable urban development, especially in the largely urbanising areas, to transition towards the use of renewable energy in smart cities.

6.2. Recommendations

The following recommendations are suggested basing on the findings:

6.2.1. Increase the Renewable Energy Implementation

Increasing the investments in solar, wind, and biomass energy should be made by governments in order to decrease emissions and enhance the resilience of the cities.

6.2.2. Speed up Smart city development

Smart grids, smart movement, waste-to-energy plans, digital sensors, and AI-controlled that manage resources should be implemented in cities.

6.2.3. Enhance Climate Governance

Develop clear monitoring systems, climate action laws, and proper regulatory bodies to enhance project performance.

6.2.4. Invest in More Climate Technologies

The additional resources should be spent on the research and initiatives of developing sustainable technologies as well as deploying them especially by governments and development partners.

Compliance with ethical standards

Disclosure of conflict of interest

No Conflict of Interest to be disclosed.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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