

# **A STUDY OF GREEN TECHNOLOGICAL INNOVATION: EMPIRICAL EVIDENCE ON SMART CITIES AND GREEN DEVELOPMENT**

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## ***Abstract***

*The paper discusses how the efforts of smart city development and green technology innovation influence Ludhiana, Punjab's green development. On the basis of a multiple linear regression model, ten critical variables have been considered: investment in green technology, digital infrastructure, awareness among public, support of policy, energy consumption efficiency, waste management infrastructure, urban mobility measures, water management resources, economic incentives, and people participation. The results identify a positive and strong effect of the variables on the Green Development Index (GDI), which captures 85.6% of its variance. Policy support, digital infrastructure, and green technology investment were found to be key drivers of sustainable urbanization. The research gives prominence to strategic urban planning, technological innovation, and proactive community participation in attaining environmental sustainability. It yields valuable inputs to policymakers and planners alike, in pointing toward integral urban government. It is one of the earliest contributions in presenting empirical proof that draws evidence from the developing world economy scenario to direct smart city and green urban planning futures.*

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## **1. INTRODUCTION**

Ongoing urbanization poses challenges for underdeveloped economies in meeting rising energy and environmental demands due to increasing urban populations (Dasgupta et al., 2024). The concept of smart cities represents a progressive stage of urbanization, providing a new framework for urban development that leverages digital technologies to improve urban transport, water supply, waste management, and building efficiency. A key objective of smart cities is to promote sustainable development, which is characterized by economic growth that enhances human well-being while addressing environmental issues (Liu et al., 2023). This includes investments in renewable energy and the transition to low-carbon, efficient production methods (UNDP, 2021). Smart cities fundamentally integrate green technology innovations aimed at improving energy efficiency and reducing pollution (Khan et al., 2021). Thus, green technology innovation is vital for understanding the relationship between smart cities and sustainable development (Yan 2023).

## **2. BACKGROUND AND RATIONALE**

Smart city construction is a significant step towards green economic growth and sustainable

development. Zhang et al. (2023) analyzed the data from 221 prefecture-level cities from 2006 to 2020 found that smart city construction significantly contributes to urban green development through industrial structure and green technology innovation. It also has a positive spatial spillover effect, promoting local green development while also contributing to neighboring regions. Known as Punjab's industrial center, Ludhiana is one of the cities in India that is urbanizing the fastest. Numerous environmental issues have been confronted by it, including elevated air pollution, inadequate waste management, and rising energy demands. Urban sustainability and public health are being impacted by the extreme environmental strain caused by the fast expansion of industry and urbanization. In order to address these issues, Ludhiana has been included in the Indian government's Smart Cities Mission, which aims to transform the city into a sustainable metropolitan center by utilizing green technology, digital infrastructure, and intelligent urban design.

The coming together of smart city projects and green technology is very important for green development in Ludhiana. Smart tools like IoT-based systems for checking the environment, smart power grids, and digital systems for waste can help use resources better and reduce harm to nature. Use of Advanced technologies which are environmentally friendly assists the cities to become more cleaner by producing less carbon emission and saving energy. However, there is not much research available about how well these things work for green development in Ludhiana.

This research aims to address this research gap by exploring the role of smart city measures and green technological innovation in green development in Ludhiana. This research intends to study the impact of smart city projects and green technological innovation on green development in Ludhiana. Specifically, the research intends to Explore the impact of Investment in Green Technologies, Digital Infrastructure, Public Awareness, Policy Support, Energy Consumption Efficiency, Waste Management Systems, Urban Mobility Solutions, Water Resource Management, Economic Incentives, and Community Engagement on the Green Development Index.

### **3. THEORETICAL FRAMEWORK**

The theory of innovation diffusion and the approach to sustainable urban development are the foundations of this study, which places an emphasis on the combination of social, economic, and environmental factors in urban planning with the purpose of achieving long-term sustainability. Investing in green technologies, public awareness, economic incentives, policy support, digital infrastructure, energy consumption efficiency, urban mobility solutions, waste management systems, water resource management, and community engagement are the ten variables that are utilized by the research in order to evaluate the role that smart city projects and green technological innovation play in the process of green development in Ludhiana.

As the world keeps urbanizing (United Nations, 2019), most economies struggle to meet increasing

energy and environmental needs. Smart cities, which entail green technological advancements, are a high level of urbanization that seeks to pursue green development (Dasgupta et al., 2021; Kummitha, 2019; Yigitcanlar and Kamruzzaman, 2018). Green development performance is manifested in environmental quality enhancement, structure performance, production performance, and technology performance.

Smart city construction can result in advances in green development performance, with evidence from research revealing decreases in air and water pollution, increased environmental resilience, and increased energy efficiency. Nevertheless, the technological innovation impact of smart cities reveals that they can bring capital and labor inputs to R&D operations and render technological advances adopted and spread by the economy (Khan et al., 2021).

green technological innovation is more suitable for green development compared to total technological innovation and grimy innovation. Awareness of the influence of smart cities on green technological innovation is significant in order to attain long-term sustainability and supporting sustainable urban development. Fernando et al., (2019) established drivers such as remuneration, contributions of society and business community, political support, and motivation of staff for proper implementation of SWM program. Strong legal framework, raising awareness, encouragement of labor force, and technology development are recommendations. Sun, Q. (2024) explored the impact of smart city construction on green innovation and industrial emission reduction and found a positive relationship between smart city construction and green innovation, with indirect channels including labor factor allocation, venture capital attractiveness, and market accessibility. The findings suggest smart city construction offers a digital dividend for green innovation and sustainable development. Further Hui et al., (2023) explored the integration of urban natural resources and smart city technologies to promote sustainability. Green spaces can serve as renewable energy sources, natural filters, and public spaces, but effective management requires smart technologies like sensors. Challenges include cost, reliability, privacy, and expertise. Strategies like air quality sensors, green infrastructure, and transit-oriented development can improve air quality and health. Advanced technologies like smart grids and renewable energy can manage sustainable resources.

#### **4. RESEARCH GAP**

Despite increased attention to smart cities and green technological innovation, empirical evidence of their effect on green growth is still scarce, especially in emerging economies such as India. Most research has been conducted on developed nations with little concern for the specific socio-economic and environmental issues of Indian cities. Ludhiana, being a city and an industrial hub, offers a distinctive setting to explore the success of smart city policies in encouraging green development. Being part of the Smart Cities Mission and having environmental issues, the city is the best case to

study the effects of green technological innovation on the sustainability of a city.

In addition, existing studies have also largely examined single pillars of smart cities, including energy efficiency or waste management, without taking into account the combined effect of a series of smart city projects on green development. The present study fills this research gap by taking an overall perspective, examining the combined influence of ten crucial variables on the Green Development Index (GDI). The GDI is a composite index that captures air quality, energy efficiency, waste management, and availability of green spaces and gives an integrated view of the outcomes of green development.

This study adds to the body of literature by providing empirical insights on the impact of smart city projects in advancing green development in the context of an emerging economy. It offers useful recommendations for policymakers, urban planners, and stakeholders regarding the significance of strategic investments, regulatory environments, and community participation in sustainable urban development. The research also makes theoretical contributions to the study of innovation diffusion and sustainable urban development by analyzing the combined effect of various smart city initiatives on green development.

## **5. RESEARCH METHODOLOGY**

This research uses a quantitative approach based on a cross-sectional survey technique to explore the effect of smart city policies and green technological innovation on Ludhiana's green development, Punjab. The primary data is gathered using a structured questionnaire surveying major stakeholders, such as policymakers, urban planners, environmental specialists, and local residents directly engaged in or impacted by urban sustainability programs. It employs a purposive sampling approach to identify respondents who possess knowledge and experience in relevant areas, covering well-informed views on green technological innovation and smart city strategies. The research surveys ten influential variables such as Investment in Green Technologies, Digital Infrastructure, Public Awareness, Policy Support, Energy Consumption Efficiency, Waste Management Systems, Urban Mobility Solutions, Water Resource Management, Economic Incentives, and Community Engagement are obtained using a five-point Likert scale. The impact of independent variables on GDI is assessed using multiple regression analysis, which offers a comparative evaluation of the influence of these variables on green development. We strictly comply with ethical standards, encompassing anonymity, confidentiality, and informed consent. This research methodology aids urban planners and policymakers in advancing sustainable urbanization by offering an empirical analysis of the factors influencing green development in Ludhiana.

### Regression Results

Variable	Coefficient ( $\beta$ )	Standard Error	t-Statistic	p-Value	Significance
Constant ( $\beta_0$ )	1.872	0.295	6.35	0.000	***
Investment in Green Technologies ( $X_1$ )	0.311	0.064	4.86	0.000	***
Digital Infrastructure ( $X_2$ )	0.268	0.059	4.54	0.000	***
Public Awareness ( $X_3$ )	0.194	0.055	3.53	0.001	**
Policy Support ( $X_4$ )	0.221	0.058	3.81	0.000	***
Energy Consumption Efficiency ( $X_5$ )	0.276	0.060	4.60	0.000	***
Waste Management Systems ( $X_6$ )	0.248	0.057	4.35	0.000	***
Urban Mobility Solutions ( $X_7$ )	0.219	0.062	3.53	0.001	**
Water Resource Management ( $X_8$ )	0.185	0.053	3.49	0.001	**
Economic Incentives ( $X_9$ )	0.252	0.061	4.13	0.000	***
Community Engagement ( $X_{10}$ )	0.198	0.054	3.67	0.000	***
Adjusted ( $R^2$ )= 0.842, F Value= 61.28, P Value= <0.05					

## 6. DATA ANALYSIS AND INTERPRETATION

This research looks at how new green technologies and smart city projects have affected green growth in Ludhiana, Punjab. Ten important variables are investigated in relation to the Green Development Index (GDI), a composite index of air quality, trash management, energy economy, and availability of green areas. The basis of this investigation is a multiple linear regression model. Significantly indicating a strong link between independent factors and green development results, the model explains 85.6% of the variance in GDI. Below are thorough explanations of the effects of every variable.

According to the survey, one of the main factors behind green development in Ludhiana is financial support for ecologically friendly technologies. With a positive coefficient of 0.311 ( $p < 0.001$ ) the

regression findings suggest that the Green Development Index increases by 31.1% for every unit increase in green technology investment. This result is consistent with earlier studies underlining the contribution of renewable energy technology to reduce carbon emissions and advance sustainability (Sharma et al., 2022). Since more money is being invested in solar power plants and electric cars, Ludhiana uses less energy and boasts better air quality. This study suggests that government and businesses working together and providing economic incentives like solar panels and electric automobiles will help to increase the usage of green technologies among more people. Furthermore shown by the results is the need of creating an environment fit for investing in order to enable sustainable growth of cities.

The results indicate that green development is highly influenced by digital infrastructure. This is evident from a positive value of 0.268 ( $p < 0.001$ ). Better digital infrastructure that which includes IoT devices, smart meters, fast internet helps to raise the Green Development Index (GDI) by 26.8%. These findings reveal that improved utilization of resources and environmental protection depend on digital transformations.

Smart metering systems in Ludhiana and IoT-based waste management have cut energy consumption and garbage collecting paths to lessen running costs and environmental effect. Smart urbanization calls for digitalization, according to earlier studies (Jain & Gupta, 2023). The study implies that funding digital infrastructure will help to enhance predictive analytics for energy and water management as well as data-driven city planning.

According to the research, green development is much supported when people are more conscious of and interested in environmental preservation. This is demonstrated by a high value of 0.194 ( $p = 0.001$ ), so public awareness can increase the Green Development Index (GDI) by 19.4%. Stated differently, sustainable development is better off the more people care about the surroundings. Local organizations in Ludhiana have started initiatives like waste sorting, energy saving, and promotion of environmentally responsible behavior. These behaviors have enabled individuals to live in surroundings more ecologically friendly. This aligns with what past studies previously revealed that preserving the environment depends on community involvement (Singh et al., 2021). The report advises developing policies emphasizing on educating people and leveraging social media to raise awareness and include more people in order to support this.

Using a coefficient of 0.221 ( $p < 0.001$ ), the analysis reveals that policy support including government policies and green development incentives significantly affects the GDI. The 22.1% rise in green development resulting from a one-unit increase in policy support attests to the efficiency of government and policy direction. Laws encouraging green development in Ludhiana such as tax subsidies for renewable energy projects, tight management of industrial emissions, and incentives for

electric vehicles have had a positive impact. This outcome is consistent with research showing how well defined regulations promote environmental friendly behavior. The paper claims that consistent policy application and improved regulatory compliance are prerequisites for better green urbanization.

With a coefficient of 0.276 with great relevance ( $p < 0.001$ ), the regression results imply that energy consumption efficiency performs a powerful and positive function in fostering green development. Simply said, the Green Development Index (GDI) usually increases when energy efficiency rises by roughly 27.6%, based on the statistics. Ludhiana's practical initiatives in energy-saving appliances, LED lights, and smart grid technologies have already clearly cut emissions and energy use. These results fit very nicely with past studies stressing the environmental benefits of improved energy use (Bhatt & Mehta, 2024). The research underlines how important it is to support low-energy technologies and energy-saving programs if cities are to develop sustainably.

Urban mobility solutions also play a vital role in green development with a coefficient of 0.219 ( $p = 0.001$ ). According to the research, sustainable mobility options in the urban area such as electric cars, intelligent public transport, and cycling infrastructure promote an increase in the GDI by 21.9%. Ludhiana has adopted means such as electric bus fleets, bike-sharing programs, and walking spaces, facilitating less traffic and emission. The conclusions are in line with research highlighting the environmental benefits of sustainable urban mobility. The research indicates improving public transport, increasing electric vehicle charging facilities, and encouraging non-motorized means of transport.

A positive effect of water resource management on green development was discovered by the study, which was indicated by a coefficient of 0.185 ( $p = 0.001$ ). Effective water management measures result in an 18.5% boost in the GDI. Smart water grids, rainwater harvesting, and wastewater recycling initiatives have helped Ludhiana achieve water conservation and environmental sustainability. These findings are consistent with urban sustainable water management research. The research recommends encouraging cutting-edge water management technologies and public participation for sustainable water practices.

The regression analysis shows that economic incentives have a positive effect on green development, with a coefficient value of 0.252 ( $p < 0.001$ ). Financial gains and subsidies increased the GDI by 25.2%. Economic incentives to use renewable energy and electric vehicles have driven Ludhiana's green transformation. The conclusion holds in line with other research findings on economic policies favoring sustainable urbanization. The research advises improving economic incentives to promote the adoption of green technology. Community participation has a positive influence on green development, with a coefficient of 0.198 ( $p < 0.001$ ). Citizen participation increases the GDI by

19.8%, highlighting social sustainability and popular support. Ludhiana's green development policy is enriched by community participation in environmental projects. The research advises developing community-based sustainability initiatives and participatory urban governance.

## 7. CONCLUSION

The research concluded that smart city projects contribute greatly towards green development in Ludhiana, Punjab, and key drivers for such development include investment in green technology, digital infrastructure, policy support and community participation. Regression analysis indicated that these variables had a strong positive effect on the Green Development Index, explaining 85.6% of the variance in the Green Development Index. These findings underscore the importance of strategic urban planning and technological advancement in achieving environmental sustainability and improving the quality of urban life.

### Implications

The findings, according to the study, will benefit policymakers and urban planners in Ludhiana, as well as in other cities. Boosting sustainable urbanization can benefit from promoting the nature of the public-private sector, increasing investments in green technologies and enhancing the digitalization of infrastructure. However, conservation allocations depend heavily on stable policy settings, economic incentives, and active involvement by communities to drive awareness and behavioural changes

### Limitations

In spite of its thorough analysis, this research has some limitations. First, the cross-sectional study design limits inferences about the causal relationship between smart city projects and green development. In addition, the study is limited to Ludhiana only which may affect the generalizability of the findings to other settings with different socio-economic and environmental factors. Future research should consider longitudinal data and analyses of multiple cities to enhance the strength of findings and provide a broad perspective.

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