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Micro Level Mobility Intervention in Urban Spatial Structure in Reducing GHG Emissions: A Case of The City of Lucknow, Prayagraj and Varanasi

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Abstract

In contemporary times, the Greenhouse Effect has emerged as a paramount concern in urban areas. With India undergoing rapid urbanization, cities are witnessing soaring temperatures. Greenhouse gas emissions are one of the main causes of the Greenhouse Effect. India stands among the highest emitters of GHGs, primarily stemming from the energy sector, particularly in electricity generation. The period from 2005 to 2018 saw a noteworthy surge in India's emissions, largely due to coal-based power production. While India's per capita GHG emissions remain relatively low, the increase in these gases exerts detrimental effects on global temperatures, underscoring the need for localized interventions to drive large-scale change. A study conducted in Lucknow, Prayagraj (Allahabad), and Varanasi scrutinized various determinants influencing GHG emissions. The analysis includes factors such as road network, vehicle count, transportation hubs, and green spaces. Significant correlations between these variables and GHG emissions were discovered through the use of a multilinear regression model. Additionally, coefficient analysis and assessment of variance inflation factors further substantiated the validity of the model. This paper focuses on emphasizing the collective effort required to achieve a low-carbon cities and prioritizing proper mixed use development.

Keywords: Urban planning, mixed-use development, mobility planning

INTRODUCTION

According to a recent landmark United Nations (UN) research, "harmful carbon emissions from 2010 to 2019 have never been higher in human history," and the globe is on a "fast track" to disaster [5]. The urban population has been increasing rapidly and is anticipated to reach ten billion by 2100 when about 90% of people would live in cities. It is widely acknowledged that rapid urbanization is a sign of industrialization and successful growth. Excess carbon dioxide, a consequence of urbanization, can cause global warming and a variety of other environmental issues. Cities generate more than 70% of CO_2 emissions and use more than 66% of energy [6]. Building low-carbon cities is essential to lowering human-caused carbon emissions and lessening the greenhouse effect. A comprehensive understanding of the connection between urbanization and carbon emissions is necessary to build low-carbon cities. Urbanization is a complex socioeconomic phenomenon that results from a number of factors, such as shifts in population, lifestyle, and land use. Carbon emissions intensity, per capita carbon emissions, and aggregate carbon emissions are all closely associated with urbanization [4]. The urban ecosystem has numerous sources of carbon emissions. The energy sector in India accounts for the largest percentage of Green House Gas (GHG) emissions, followed by waste, industrial processes,

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land-use change and forestry, and agriculture, which comprise 19.6%, 6.0, 3.8, and 1.9% of GHG emissions, respectively [1]. According to GHG emissions in India, the waste from industries, Industrial Processes, and Product Use (IPPU) sectors contributed 6% and Agriculture, Forestry, and Other Land Use (AFOLU) sector 16% of total emissions in 2005.When compared statistically, from 1585.51 Mt CO_2e in 2005 to 2952.87 Mt CO_2e in 2018, India's emissions increased at a CAGR of 4.90% [1].

The reason behind the dynamic change is Electricity. India's reliance on coal-based power facilities makes electricity the primary source of its carbon emissions: A third of India's total greenhouse gas emissions came from coal, which also provides 74% of the nation's electricity Figure 1-5 [6].

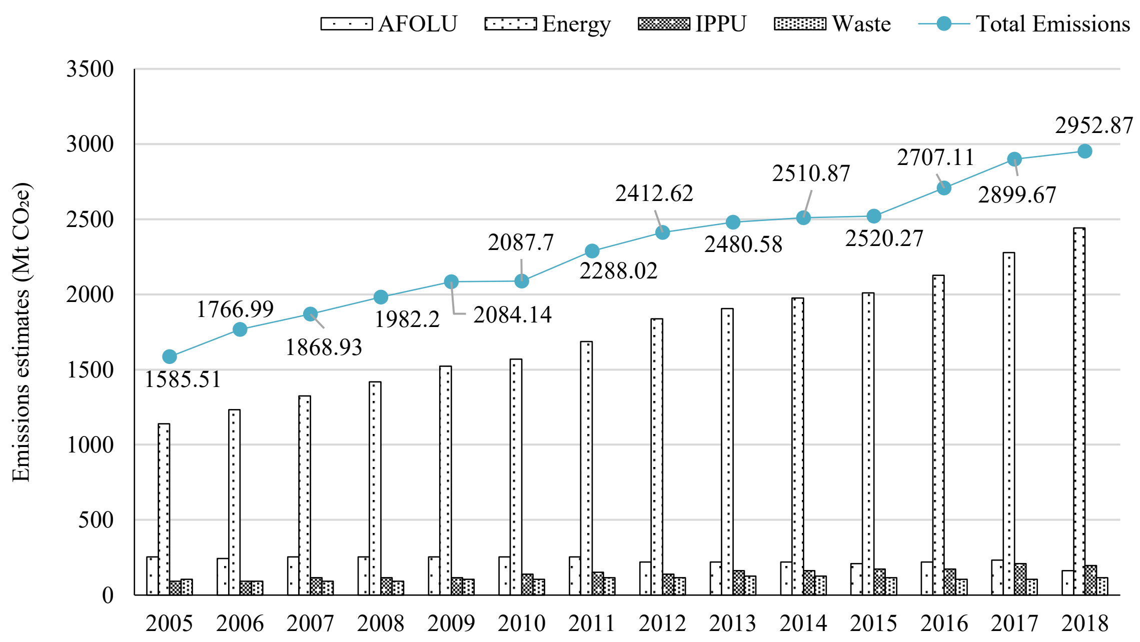

Figure 1. Global CO2 Emission year wise (Source w.r.t Author).

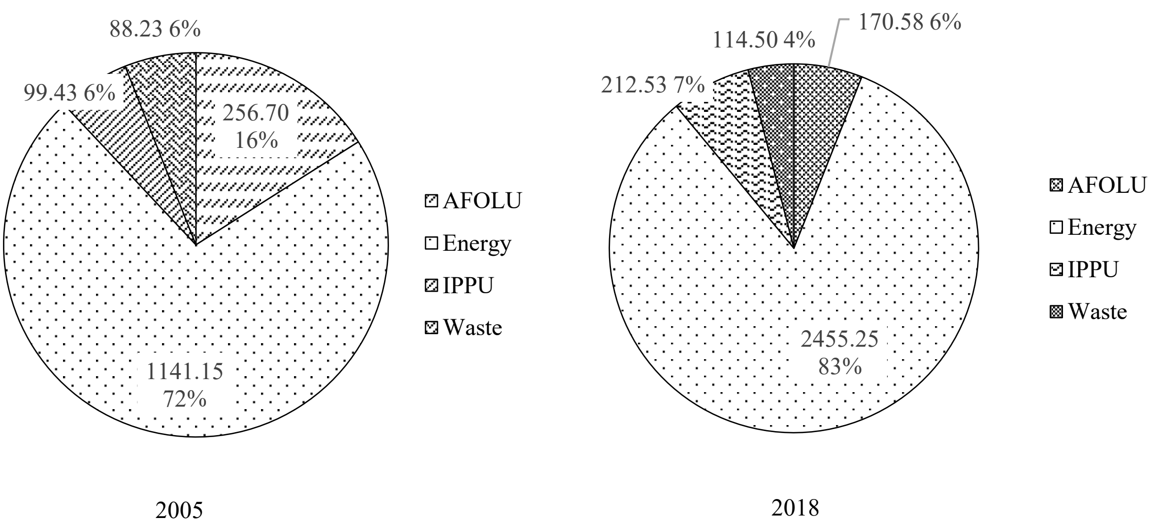

Figure 2. CO2 emission comparison 2005 – 2018.

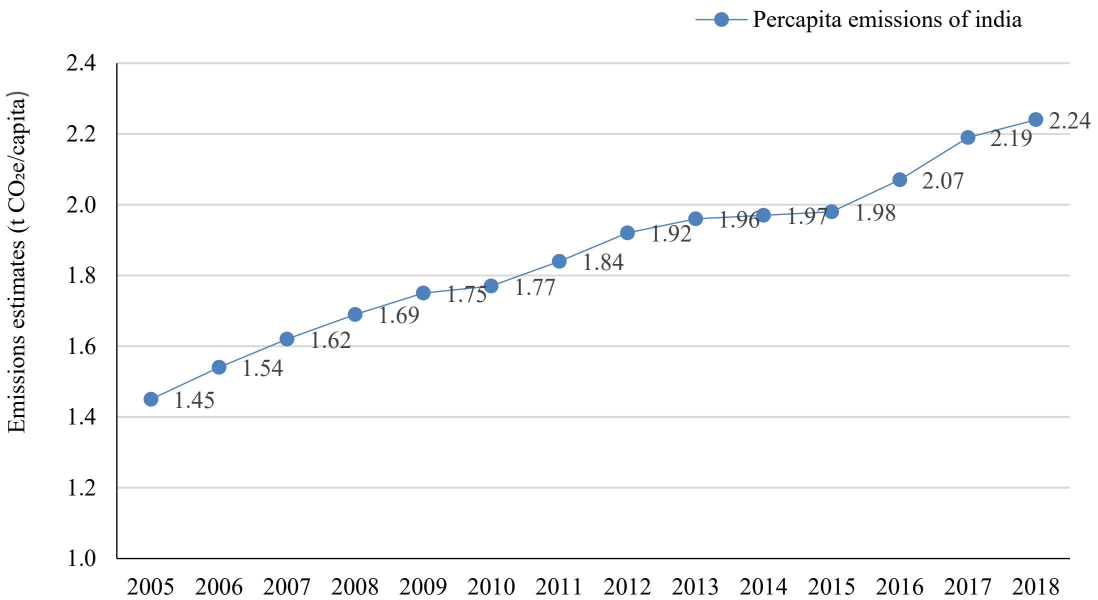

Figure 3. CO_2 Emission per capita in India (Source w.r.t Author).

In 2020, the average amount of greenhouse gases released per person in the globe, including land use, land-use change, and forestry, was 6.3 tCO_2e (ton carbon dioxide equivalent). India is toward the bottom of the global CO_2 emitters, nevertheless, with emissions per person that are much lower when historical emissions per person are taken into account. In terms of energy use, the typical Indian household uses a tenth of the power used by the typical American household [1].

However, as greenhouse gas concentrations increase the earth's average surface temperature gradually rises as well. Sea level, storm frequency, and precipitation patterns may potentially fluctuate as a consequence of rising temperatures [3]. According to the COP27, nations reiterated their commitment to keeping the increase in global temperatures to 1.5°C over pre-industrial levels in a package of resolutions [3]. Therefore, in order to reflect changes at the macro level and tend to lower the general temperature, this issue must be enhanced at the micro level. According to this study, altering a region's urban spatial form may help lower GHG emissions at the micro level [4].

Urban Spatial Structure and Behavior Dynamics of Residents

The urban spatial structure takes into account where various activities are located in both the center and the periphery. The cities' functional spaces and the effectiveness of people participating in socioeconomic activities are impacted by human activities that alter the natural environment, reflect changes in the natural environment, and reflect population migrations and industrial activity [4].

Classic theoretical urban economic models describe monocentric urban spatial structure, in which land price, employment and population all decline with the distance from Central Business District (CBD) [8]. Over the second half of the last century, jobs and population have been constantly decentralizing, significant portion of which have re-concentrated in new job centers. These changes of urban structure have had profound influences on travel behavior and residential energy consumption [17]. There are two dimensions of urban area-level spatial structure centralized versus decentralized structure and clustered versus dispersed structure.

Role of Urban Mobility in Spatial Structure

The International Energy Agency (IEA) and Intergovernmental Panel on Climate Change (IPCC) data and estimates report that the transport sector accounts for a significant share of worldwide energy consumption and greenhouse gas (GHG) emissions [6].

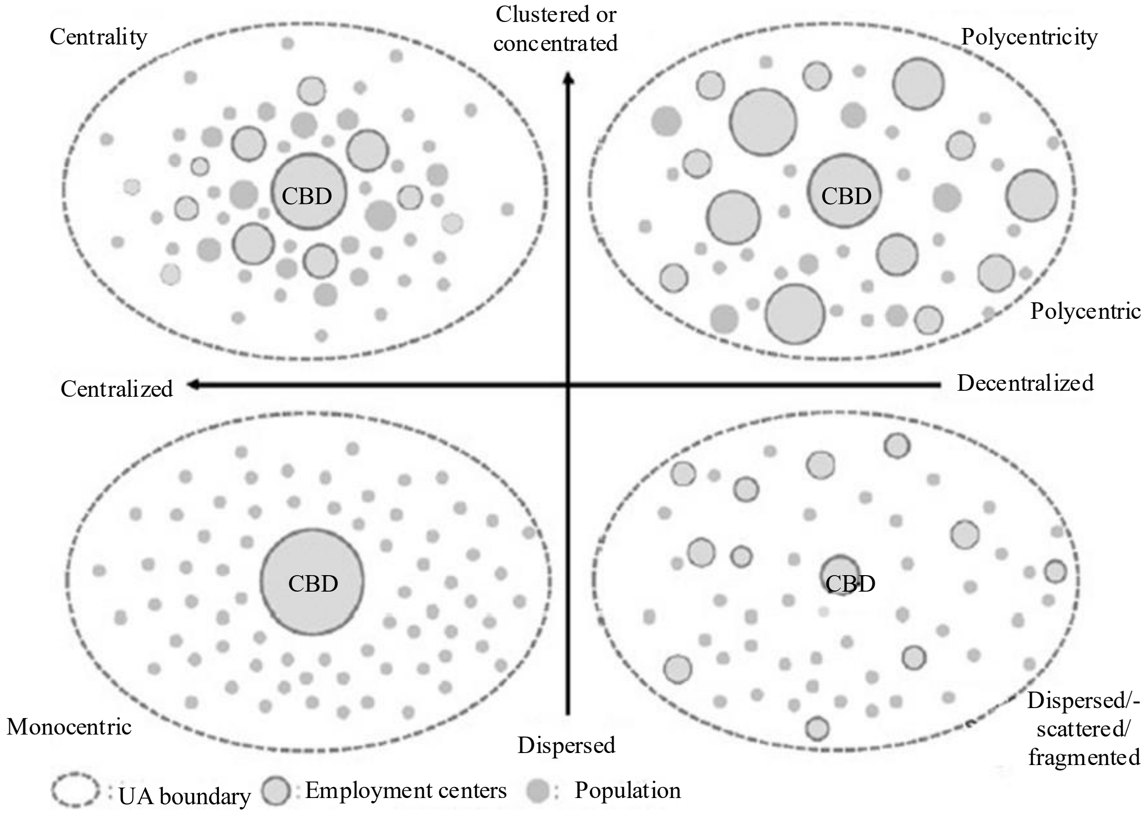

Figure 4. The classification of urban spatial structure with two dimensions (Source w.r.t Author).

To better comprehend the relationship between urban structure and mobility, the three dimensions of urban structure are examined. Urban structure and transportation are closely intertwined aspects of a city's design and functionality. They play a crucial role in shaping how people move within and interact with urban environments. [4]

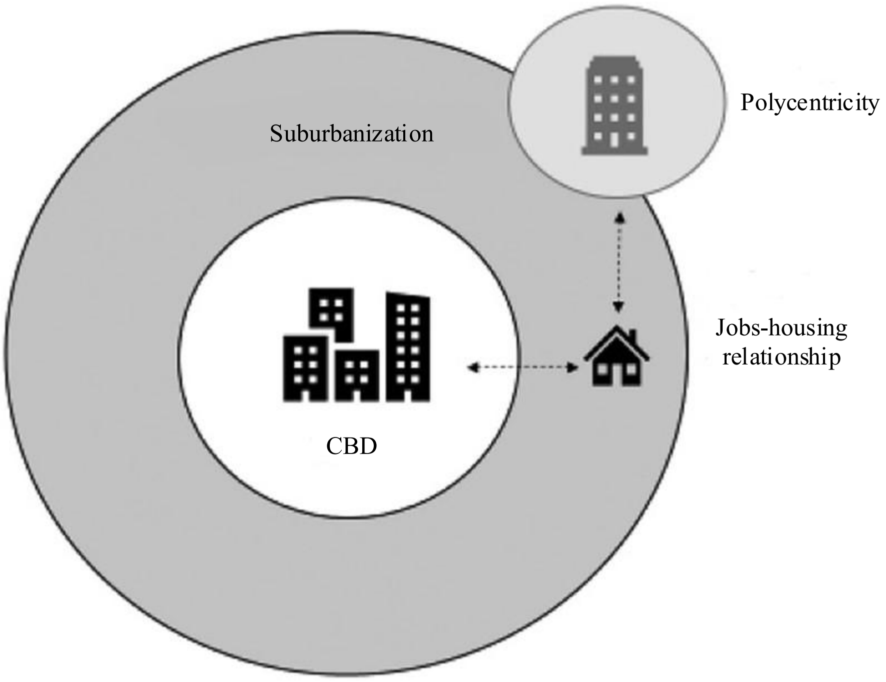

Figure 5. Polycentricism of a town (Source w.r.t Author).

The means of increased in non-green mobility directs towards increase in per capita generation of GHC. Road transport uses 90% of the energy used by the Indian transportation industry, which is accountable for 13.5% of the country's energy-related emissions [10]. Road safety and easily accessible public transportation are also essential for decarbonizing Indian cities.

The determinants of transportation linked to urban structure are as followed:

- Zoning and Land Use
- Density and Mixed-Use Development
- Transportation Hubs
- Road Network
- Public Transportation
- Active Transportation
- Last-Mile Connectivity
- Parking
- Green Spaces and Public Plazas
- Environmental Considerations
- Number of vehicles

Hence, to study the integration of urban mobility a comprehensive comparative study has to be performed between the character of the city and Carbon generating factor. The interpretation of the case could be lack of public transportation/ accessibility leads to more private vehicles in a city figure 6[10].

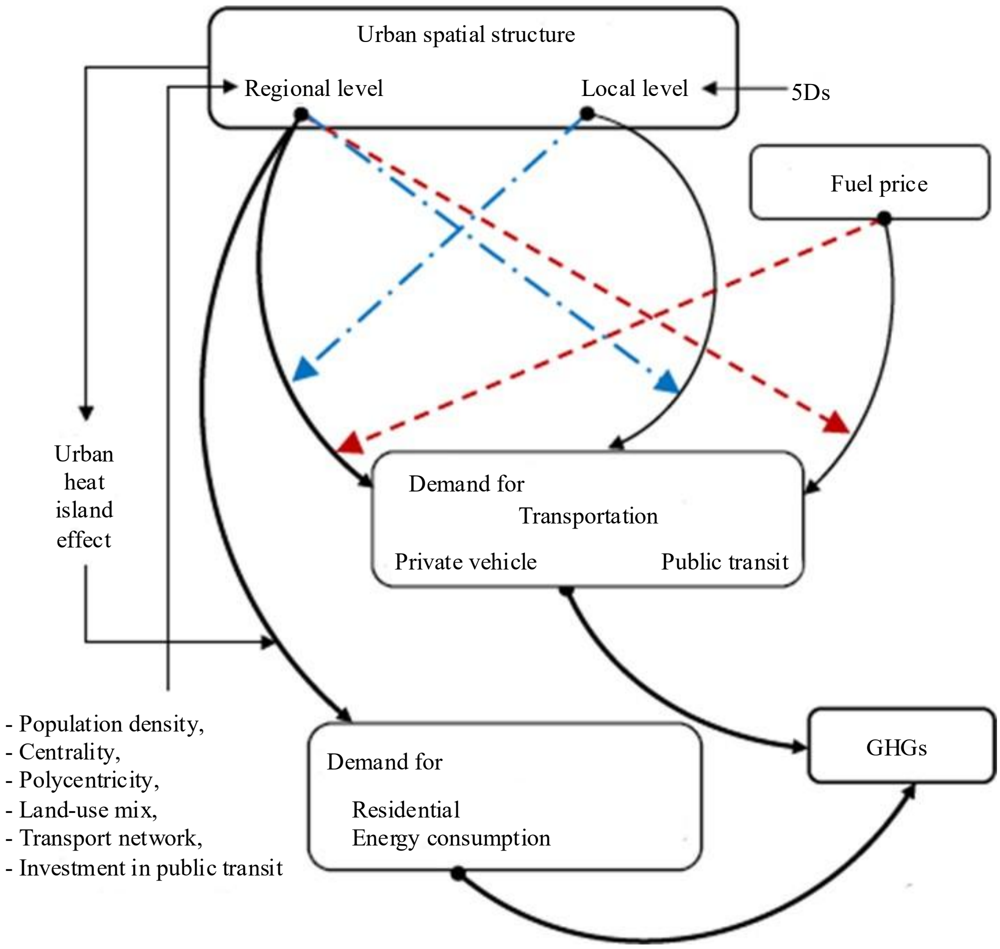

Figure 6. Urban spatial structure nature with mobility.
(Source w.r.t Author)

INVESTIGATION

This study has been conducted strictly considering the Municipal Boundary, of Lucknow, Prayagraj (Allahabad) and Varanasi.

The emission for each city is recorded form secondary sources, the other data sources for the data collected includes PARIVAHAN (Vehical Directory), and Master Plan/Reports of the cities [11], [12], [20]. The following data is collected.

Multivariate multiple regression is the technique of modeling several components, or dependent variables, with a single set of predictors. It regresses each dependent variable on the predictors separately. The following regression uses the Enter regression approach [13].

Analysis of Coefficient

The variance inflation factor (VIF) is a metric that measures how much multicollinearity exists in a set of multivariate regression variables. According to a commonly used rule of thumb, a VIF larger than ten indicates significant multicollinearity. The regression is reasonable in this example, with values around 0.69 table 1-4.

Table 1. Nature of determinants.

S no	Determinants	Nature of determinant	Units of determinants
1.	GHG Emission	Carbon generated by a city per year.	g/km/hr
2.	Length of Road Network	Length of total motor able road of the city.	(Km)Kilometer
3.	Number of vehicles	Total Number of Private Vehicles register under the RTO of the city	Number
4.	Transportation Hubs	Total Number of Transport hub including Airport, Railway Station, Bus stand and NMT/Paratransit Stands	Number
5.	Modal Split of Public Vehicles	Total vehicles registered under public mode in the RTO of the city.	Number
6.	Density of the city	The net residential density of the city.	Household / Sq. km
7.	Last mile connectivity	Total number of vehicles registered under Paratransit and NMT.	Number
8.	Green Space	Total area of the city under Green and open	Sq Km
9.	Water Body	Total area of the city under water bodies and wet lands	Sq Km
10.	Mixed Land-use	Total area under Mixed land use	Sq Km

Source: Author

Table 2. Absolute values of determinants.

City	GHG emission	Municipal area	Length of road network	Number of vehicles	Transportation hubs	Modal split of public vehicles	Last mile connectivity	Green space	Water body	Mixed land use
Lucknow	491,937	348	3387	84,574	35	257	12,535	9.98	0.02	0.79
Varanasi	277,125	267.48	1180	54,202	28	347	9,166	34.43	9.80	19.45
Prayagraj	292,781	309.17	2357	64,587	16	213	7,654	49.53	40.99	32.34

Source: Author

Table 3. Weightage score out of 100

City	GHG emission	Municipal area	Length of road network	Number of vehicles	Transportation hubs	Modal Split of public vehicles	Last mile connectivity	Green space	Water body	Mixed land use
Lucknow	46.33	37.64	48.92	41.59	44.30	31.46	42.70	10.62	0.05	1.50
Varanasi	26.10	28.93	17.04	26.65	35.44	42.47	31.22	36.65	19.29	36.99
Prayagraj	27.57	33.44	34.04	31.76	20.25	26.07	26.07	52.73	80.67	61.51

Source: Author

Table 4. Coeff. analysis table

Coefficients									
Model	Unstandardized B	Coefficients Std. error	Standardized coefficients beta	t	Sig.	95.0% Confidence lower bound	Interval for B upper bound	Collinearity tolerance	Statistics VIF
1(Constant	27.289	.000				27.289	27.289		
L road	.396	.000	.560			.396	.396	.690	1.449
M_LU	-.214	.000	-.574			.214	.214	.690	1.449
2(Constant)	33.333	6.512		5.119	.036	5.314	61.353		
a. Dependent Variable: GHG_E									

(Source: Author).

Hence the relationship between the variable could be depicted such as –
GHG_E = 0.396 (L_Road) + (-) 0.214 M_LU + 33.33

According to the analysis, GHG emissions are negatively proportional to mixed land use. As a result, to reduce GHG emissions, spatial structure changes should be made to mixed land use, as mixed land use creates incoming traffic due to its changeable character, and improvisation on the road network is proposed to reduce congestion and maintain smooth traffic flow [7], [14].

Recommendation

The findings of this comprehensive study shed light on the critical relationship between urbanization, carbon emissions, and Urban Mobility. Prioritization on Low-Carbon City Construction is recommended as cities are responsible for over 70% of CO_2 emissions, which would include reduced dependency on thermal power generation. It is imperative to invest in and transition to cleaner, renewable energy sources. This will not only reduce emissions but also promote a healthier environment. Encouraging the use of public transportation based on E-Mobility based solution, developing efficient and accessible transport hubs, and promoting active transportation modes are key strategies to reduce per capita GHG emissions. Urban Structure and Mobility Planning thus interplay between urban spatial structure and mobility patterns which include Zoning, land use, density, and transportation hubs should be strategically planned to minimize emissions. Additionally, prioritizing green spaces, pedestrian-friendly infrastructure, and last-mile connectivity will contribute to a more sustainable urban environment. [15][16].

The study hereby directs for strategically planned Mixed Land Use as the analysis demonstrates a negative correlation between mixed land use and GHG emissions. Encouraging mixed-use development can lead to reduced inbound traffic and, subsequently, lower emissions. This approach fosters a balanced and dynamic urban environment [14], [17].

The following recommendations are framed

- Review local zoning ordinances and regulations to allow for mixed-use construction. If necessary, the local authorities should modify or create zoning ordinances that accommodate mixed-use projects

- *Traffic and parking planning*: To Evaluate traffic flow and parking needs to ensure the development is accessible and convenient for all users. Consider provisions for pedestrian-friendly infrastructure, such as sidewalks, crosswalks, and bike lanes.
- *Public spaces and amenities*: Design and allocate spaces for parks, plazas, courtyards, and other communal areas. Integrate green spaces and public art to enhance the overall environment.
- *Infrastructure and utilities:* To Ensure that the necessary infrastructure, such as water, sewage, electricity, and internet connectivity, can support the development [18].

In conclusion, the findings of this study provide insights into the complex relationship between urbanization, carbon emissions, and spatial structure. By implementing the recommended strategies, cities can take significant strides towards achieving a low-carbon and sustainable future. This collective effort is not only crucial for the well-being of urban populations but also for the health of the planet as a whole.

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