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Towards Sustainable Urban Planning: Analyzing Socio-Economic Impacts On Ecological Footprints In Lahore

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Abstract

Resource consumption in the urban environment has risen from lack of planning to the extent that environmental degradation and ecological footprints are problematic. To deal with ecological sustainability, we need to understand the fallouts of consumption patterns, consumption of energy, transportation and the level of waste generation. The aim of this study is the analysis of ecological footprint of urban areas through data driven approach based on the

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surveyed data and computational modeling in MATLAB. The research considers the differences in ecological impact based on socio-economic factors in a low-income urban area (Begampura, Lahore). Primary data on household consumption behaviors which include meat consumption, electricity usage, waste production, and transportation behaviors were collected through a structured survey. Statistical methods were used to analyze the collected data and a multiple regression model was created in SPSS & MATLAB to predict levels of ecological footprint. The results show electricity consumption as the major factor affecting ecological footprint, with meat consumption and waste generation next. The ecological footprint was found to be relatively higher for households with a higher income because they used more energy and relied more on private transportation. The solution is then found to be to promote energy efficient appliances, reduce meat consumption, improve waste management, and enhance public transportation infrastructure to minimize environment impact. The sustainable housing models and integrated land use policies should be the focal point of urban planning so that resources may be conserved. The ecological footprints implied by the study are such that targeted interventions, policy changes and community engagement are necessary to achieve urban sustainability. These efforts will reduce environmental problems and promote more environmentally sustainable urban development.

Keywords: Ecological footprint, urban sustainability, energy consumption, waste management, MATLAB modeling, sustainable urban planning.

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Introduction

The rapid expansion of urban populations and increasing consumption of natural resources have led to significant environmental concerns worldwide. City expansion causes the ecological footprint to grow larger than natural regeneration capabilities enabling human activities. Elevated resource consumption leads to environmental destruction which produces deforestation that together with air and water pollution and climate change problems. Developing countries need to resolve their economic expansion versus environmental conservation struggle because their growing cities demand more power and generate larger waste amounts and exhaust resources. The urban development in Pakistan is accelerating rapidly because experts predict that by 2025 fifty percent of the total population will settle in cities. The severe environmental problems in Pakistan including excessive carbon emissions and inefficient waste management require effective management of ecological footprints because the country depends heavily on non-renewable energy.

Urbanization creates a primary issue where different income groups in cities use natural resources in uneven proportions. Coherent community practices define high-income areas as they display a massive ecological footprint because of their vehicle-heavy transportation system while maintaining energy-intensive households. The combination of inadequate infrastructure and dependency on power-inefficient resources with defective waste management practices can result in ecological decline throughout low-income areas. Scarce field research exists which examines how distinct

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economic groups from urban areas affect ecological footprint levels in developing nations. The targeting of sustainability measures alongside social and economic growth becomes problematic because policymakers lack sufficient knowledge of current consumption patterns in the city.

The analysis of ecological footprint across multiple urban areas will use SPSS & MATLAB-based computational modeling combined with empirical dataset analysis for comparison. This research investigates environmental implications throughout different social and economic groups to discover what variables especially influence environmental impact through energy use and waste methods and travel behavior. The research collects survey data from three distinct urban settlements Begumpura (low-income) and Garhi Shahu (middle-income) and Valencia (high-income) to examine resource consumption levels and their sustainability effects. The combination of SPSS & MATLAB-based data processing methods allows for enhanced analytical precision as well as better predictions of ecological trends in the future research project.

The primary value of this investigation involves using confirmed data to drive sustainable urban planning through its discovery of ecological footprint differences between different social economic groups. Knowledge of these varying ecological footprint measurements will let policymakers develop specific policies to boost environmentally conscious activities along with energy-saving technology deployment and waste management improvement. The research outcomes will help elevate community understanding about

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how daily patterns affect environmental sustainability. The researchers combined real-world surveys with computational modeling to achieve both scientific advancement in ecological footprint evaluation and practical solutions to solve environmental threats from urban expansion.

Literature Review

The process of urbanization results in excessive consumption of natural resources as cities utilize more than their allotted biological capacity of the planet. Human populations expansion together with increased resource usage requires the ecological footprint to serve as a fundamental sustainability assessment tool. Multiple studies reviewed ecological footprints among urban areas to show how resource usage differs through income distribution along with energy consumption and waste output and transportation systems. Most current footprint research uses static measurement methods instead of using advanced predictive modeling techniques. The research compensates for present gaps by implementing SPSS & MATLAB-based simulation along with data modeling to analyze various socio-economic urban areas' ecological footprints. This research uses Begumpura's low-income population and Garhi Shahu's middle-income and Valencia's high-income segment to generate a data-based approach for urban planning sustainability through effective environmental impact reduction strategies for policy implementation.

Computational Approaches in Ecological Footprint Analysis

The research by Kumar and Bassill (2024) studied how computational urban science together with data-driven methods benefit sustainable

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development. Their work demonstrates how ecological footprint evaluation and environmental impact and resource consumption assessments become possible through urban computing methods [1]. The research study fails to present a direct method for SPSS & MATLAB-based ecological footprint modeling which creates an opportunity for future work in simulation methods.

Kolhe et al. (2024) implemented a five-city comparative analysis of ecological footprints in India during COVID-19 pandemic times. The study employed Global Footprint Network's calculator to evaluate footprint changes while specifically identifying connections between urban density and lifestyle behaviors [2]. Despite its benefits the study lacked SPSS & MATLAB-based simulations because these simulations would make ecological footprint models more predictive and accurate.

The authors Özdamar and Yiğit (2024) conducted a study of Sakarya city environmental footprint between 2010 and 2018 which showed growing fossil fuel utilization patterns. The present research demonstrates an immediate requirement to develop new energy alternatives and stronger urban management practices for fighting resource exhaustion [3]. Their study provided thorough analysis yet did not benefit from MATLAB-based simulations to enhance explanations about footprint variations.

SPSS & MATLAB-Based Analysis for Ecological Footprint

The researchers Demirbay and Gündüz (2023) created an artificial neural network (ANN) model built in MATLAB for estimating Turkey's ecological footprint. The researchers utilized urban population size

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together with renewable energy consumption and human development index as integrated factors in their analysis [4]. The innovative research conducted analysis at the national scale for footprint measurements without comparative studies between urban areas which this study specifically targets.

The research of Chen et al. (2020) established a spatial–temporal simulation model to measure ecological footprint effects stemming from green communication technologies [5]. The authors developed computational resource models yet failed to investigate SPSS & MATLAB-based analysis of urban ecological footprints across different regions.

Zhang et al. (2022) researched the spatial and temporal changes of ecological footprints in Panzhihua China by using Net Primary Productivity (NPP). The researchers connected demographic statistics with sustainability indicators but did not include predictive MATLAB-based models for urban ecological forecasts [6]. The study implements MATLAB simulations to generate more exact footprints estimates while resolving this research gap.

Comparative Ecological Footprint Studies Across Urban Areas

Research by Hussain and Hayat (2022) demonstrated that District Swat rural residential groups maintained higher ecological footprints compared to urban areas because their farming techniques required many resources [7]. The authors establish vital information about ecological overshooting yet their research lacks predictive applications because it does not examine SPSS & MATLAB-based data-driven simulations.

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Emam (2023) studied Beheira Governorate ecological footprints in Egypt to highlight the essential role of sustainability initiatives while reporting the results in Beheira Governorate through Egypt and calcular statistic measures [8]. The analysis of environmental sustainability in the study did not include computational modeling techniques that our present research employs to deliver precise footprint measurement methods.

Gradinaru et al. (2023) conducted a study to monitor ecological footprint spatial configurations through renewable and non-renewable energy resource analysis. Their research focused on energy dependency as a leading factor behind footprints but lacked SPSS & MATLAB-based modeling that will be integrated for improved analysis throughout this research project [9].

Ecological Footprint and Industrialization

During 2011 to 2020 Iqbal et al. (2024) explored how ecological footprint consumption linked with industrialization trends as well as human development indicators throughout selected Asian countries. The authors demonstrate that economic growth leads to environmental degradation through their analysis [10]. This study targets the research gap concerning urban ecological footprint inequalities which is not covered by their findings.

Researchers at Ullah et al. (2023) studied the effects of Turkish ecological footprint on Turkey from 1970 through 2018 by examining economic growth and natural resource uses together with urbanization rates and biocapacity dynamics. The examination of historical trends in their work did not include quantitative models for

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predictive urban ecological forecasting [11]. We address the simulation limitation through MATLAB-based urban footprint prediction in our research.

Bibliometric and Historical Perspectives on Ecological Footprint

Durkaya and Kaya (2024) performed a bibliometric evaluation of scientific literature regarding ecological footprints between 2010 and 2021 which led to identifying significant patterns and major studies in the field [12]. Despite establishing strong theoretical principles the authors' study did not include empirical computational modeling until we integrated such modeling for a practical implementation of footprint examination.

The authors of Rees and Pascual [2024] returned to investigate ecological footprints through a focus on determining what human population demands from natural ecosystems. The researchers established vital information about ecological sustainability yet their work does not include real-time footprint evaluation techniques which SPSS & MATLAB models efficiently implement [13].

A bibliometric analysis dealing with ecological footprint-related publications was performed by Razzaq et al. (2023) who studied 761 documents. The authors separated their research into three main thematic sections which included sustainability and climate change and economic development aspects [14]. Their study lacks measurements of footprint data but this research connects empirical data collection with MATLAB-based simulations.

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Urbanization and Environmental Sustainability

Mallick (2024) developed the Urban Built-Up Area Footprint (UBAF) system to evaluate urban ecological sensitivity as well as bio-capacity measurement within built-up areas. The study conducted research at Siliguri Municipal Corporation to demonstrate detailed information about urban footprint behaviors [15]. This study did not use computational models for footprint simulations though our research aims to develop SPSS & MATLAB-based models.

Rana et al. (2023) analyzed ecological footprint analysis in the North Western Himalayas by studying built-up land footprint together with biocapacity to evaluate sustainability measures. The research determined ecological shortfalls yet failed to implement predictive modeling so MATLAB could serve as an effective addition to upcoming urban planning strategies according to [16].

Mir et al. (2022) conducted research on the relationship between urban expansion and resource expenditure in Sistan and Baluchestan region of Iran. The research showed that rising economic conditions lead to resource shortage and environmental degradation [17]. The current research includes MATLAB-based footprint prediction for data-driven sustainability modeling while the analyzed study did not include this system.

Policy and Sustainability Strategies for Reducing Ecological Footprints

Veselaj and Berisha (2022) examined the usage of ecological footprint analysis for shaping individual environmental conduct behaviors. The research studied Kosovo student footprints using sustainability

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education techniques [18]. The research failed to include macro-scale urban sustainability analysis although this study explores it.

This research by Hammond et al. (2022) evaluated the environmental footprint of Bath & North East Somerset by determining the footprint amounts for each resident. The study identified necessary sustainable policy measures while neglecting essential comparisons across urban areas so this research targets to bridge this gap [19].

Wang et al. (2024) deployed models for ecological footprint prediction within their research of nine Guizhou Province cities. The researcher's work contributes valuable information to sustainability planning although their study does not utilize MATLAB-based simulations that this work applies to enhance computational efficiency [20].

Research Gap

Studies about ecological footprints from various perspectives show extensive work but lack necessary use of MATLAB-based simulations to evaluate comparative urban ecological footprints. Current studies perform either basic footprint estimation through static calculations or bibliometric methods devoid of predictive computational forecasting. The study provides a solution to this research gap through its combination of survey data analysis with MATLAB modeling for investigating socio-economic disparities in urban ecology across different areas.

This research examines three types of neighborhoods called Begumpura low-income and Valencia high-income together with

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Garhi Shahu middle-income to delve deeply into the relationship between urban development and ecological footprint calculation through waste generation rates. The modeling program of MATLAB enables the creation of predictive analysis scenarios which generate useful policy recommendations for government officials.

Methodology

Research Design

A comparative quantitative research design investigates urban ecological footprints while assessing resource use and environmental effects related to socio-economic status variations. An in-depth analysis of energy usage patterns and waste production and food purchasing behavior and transportation methods operates through this study that compares between three diverse urban areas namely Begumpura (low-income) and Garhi Shahu (middle-income) and Valencia (high-income). The study establishes precise measurements of these aspects which create an unbiased evaluation between urban development and economic standing regarding ecological footprints.

The research uses data-driven processes for precise footprint studies that maintain analysis reliability. The research gathers primary information by administering structured questionnaires to directly measure actual consumption behavior of residents from chosen urban areas. The processed collected data uses MATLAB-based modeling along with simulation methods that strengthen predictive modeling of the study. The results from SPSS & MATLAB simulations display data patterns while executing statistic models to forecast ecological footprint alterations across different scenarios.

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Computational methods allow the research to evolve from performing static footprint computations to implementing dynamic modeling which evaluates sustainable trends throughout time.

The research adopts analytical methods which combine correlation assessments and regression modeling to validate its statistical quantifiable findings. SPSS & MATLAB processing enables researchers to locate major footprint variables so they can develop modeling simulations which demonstrate future resource utilization patterns. This research design creates reliable findings which enables helpful conclusions to help create sustainable urban resource handling plans. Computational modeling enables real-time analysis through scenario-based forecasting to enhance the practical value of obtained results.

Through this combination of approaches the research obtains findings that use empirical documentation as well as computational modeling to reveal advanced knowledge about the urban lifestyle and ecological sustainability connection. The multi-tiered analytical strategy gives complete visibility into footprints between economic groups while providing scientific foundations for reducing environmental impact.

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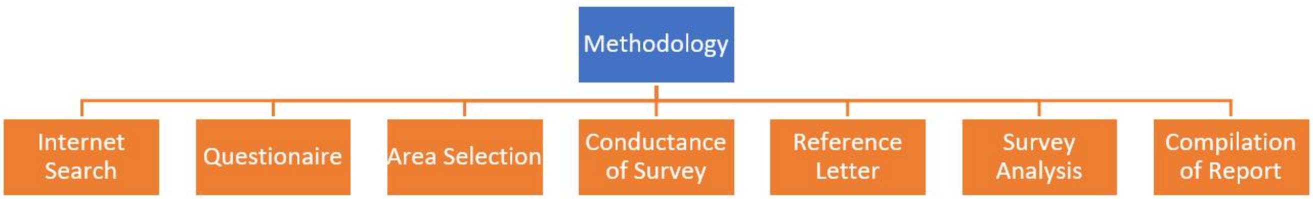

Figure 1: Research Methodology for Field Survey

Study Area Selection

The research design specified study area selection as essential because it needed to demonstrate multiple urban lifestyle patterns along with various consumer behaviors. Three distinct urban regions of Lahore Pakistan name Begumpura, Garhi Shahu and Valencia were looked at first by the study team. Researchers utilized the chosen sites to perform an analysis by studying both income level differences and how people consume resources and collect data and handle urban sustainability issues. The investigation of these geographical regions displayed extensive environmental results which enabled researchers to deeply interpret how economic elements affect ecological effects.

Begumpura: Low-Income Urban Area

Begumpura exhibits characteristics of a low-income area with crowded population and inadequate housing and limited basic amenities. Due to low household wages in Begumpura residents find it hard to acquire modern energy and experience limited waste management capacities. The affordability of resources together with dependence on non-environment-friendly energy sources and

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restrictions to electrical appliances usage and public transit and non-motorized travel define the consumption practices in this region. Begumpura's ecological footprint will present contradictory environmental impacts because its transportation sector has reduced emissions while its outdated technology combined with inadequate waste disposal systems creates higher environmental strain.

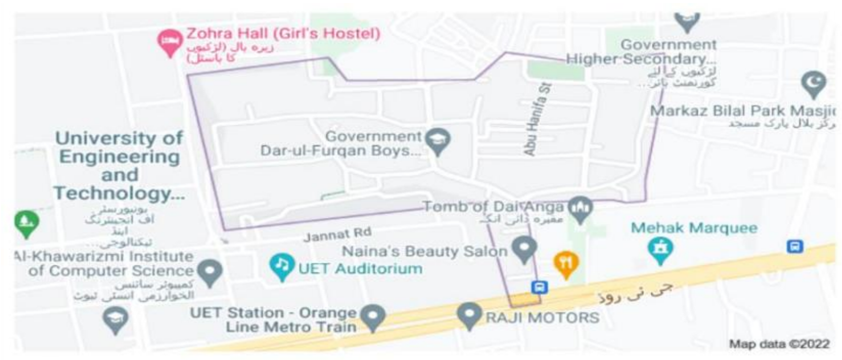

Figure 2: Begumpura: Low Income Area

Garhi Shahu: Middle-Income Urban Area

People in Garhi Shahu maintain a middle-income status because they hold stable finances that enable them to receive basic urban amenities. The neighborhood holds a combination of private automobiles with public transit services alongside well-organized residential facilities. Middle-class citizens use more energy than poor families but enjoy better access to both energy-saving technology as well as organized waste disposal facilities. The projected ecological influence of this income level lies between economical conservation practices and life-associated resource usage expansion.

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Figure 3: Garhi Shahu: Middle-Income Urban Area

Valencia: High-Income Urban Area

Residents of Valencia maintain a high-income status while using luxury houses and driving private vehicles and employing more resources. High levels of residential energy usage exist because Valencia residents live in substantial homes and run air conditioning and use different electrical devices. Households possessing wealth possess access to renewable energy choices yet their total consumption behavior leads to greater environmental impact. This location produces greater waste because its residents purchase packaged items and imported foods in increased quantities.

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Figure 4: Valencia: High-Income Urban Area

Final Selection of Study Area: Begumpura

A detailed ecological footprint analysis required Begumpura to become the main study area following the evaluation process of all three urban regions. Multiple factors served as the basis for the choice.

- Unique Sustainability Challenges: Begumpura represents a dense, low-income urban settlement where residents face energy access limitations, inefficient waste disposal, and minimal infrastructure for sustainability practices.
- Data Accessibility: The compact nature of Begumpura made survey distribution and field data collection feasible, ensuring comprehensive responses from residents.
- Higher Impact for Policy Recommendations: Since low-income communities are often overlooked in sustainability discussions, analyzing Begumpura provides valuable insights into how urban planning can mitigate environmental impacts in economically disadvantaged areas.

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The research examines Begumpura specifically to deliver targeted information regarding resource usage problems along with possible environmental solutions for disadvantaged residential areas.

Figure 5: Location of Begumpura

Data Collection Method

An approach of structured data collection was used in order to have information to work with that was as accurate and reliable as possible. The study used both primary and secondary data sources to create a complete picture of resource consumption pattern of the selected urban areas.

Primary Data Collection

The main data for this study was collected in the form of structured survey and face to face interview with residents of Begumpura, Garhi Shahu and Valencia. The questionnaire measures quantifiable information of resource consumption and environmental impact. They also solicited responses from a cross-section of people including household sizes that varied widely, economic backgrounds and

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lifestyle habits in order to have a rich dataset. Based on the surveys the key parameters that were assessed included:

Food Consumption Habits

The survey included dietary choice, meat consumption frequency, degree of dependency on processed foods, preferences for local or imported food. The energy and land needed to produce, transport and process food were used to calculate the ecological footprint of food consumption. It was also expected that households that depend more on meat and processed foods would have a larger ecological footprint because these foods are more resource intensive.

Energy Usage

This was done through energy consumption measured by household electricity used, reliance on renewable versus non renewable energy sources, and efficiency of electrical appliances. Residents were asked how much they spend a month on electricity, if they use solar panels or other renewable energy and how they save energy. In high income households, the large living spaces and a high number of electronic devices were expected to lead to higher energy consumption, while the low income households tend to use lower electricity usage, but not so efficient energy sources as biomass or kerosene.

Waste Generation Patterns

For this study, agent personal waste production was used as an indicator to investigate organic waste, plastic disposal, recycling culture, and waste segregation habits of each agent. Survey respondents were asked to estimate how much they waste each week and whether they perform waste reduction practices such as

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composting or recycling. The ecological footprint was also reduced by using waste management infrastructure and awareness campaigns at each income group to see the respective effect.

Transportation Modes and Fuel Consumption

Their frequency of use of public or private transport, fuel consumption related to commuting or other activity, and commuting distance were explored. Respondents described their travel behavior from day to day, if they own a vehicle, what they rely on for transportation and how fuel efficient are their transportation methods. It was anticipated that private car ownership would lead to higher carbon footprint and reliance on public transport or non motorized commuting would be more environmentally sustainable.

Survey Administration and Data Validation

Surveys were completed in person so data reliability could be ensured by clarification of responses and reduction of response bias. Samples of 100 urban households were targeted in order to produce a statistically significant dataset. We confirmed the data entries to collect consistency, and excluded incomplete or inconsistent responses from the analysis to assure the reliability of the data set.

Secondary Data Collection

Apart from primary data, published reports and academic journals, gray literature and government records, as well as environmental research studies, were acquired as secondary data. Contextual background and comparative benchmarks for assessing ecological footprints were sources from these. The secondary data sources included:

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Published Studies on Ecological Footprints

The results were compared to global and regional benchmarks using previous research on urban ecological footprint assessments, sustainability policies and resource consumption trends. Validation of the results of this research was done based on studies on similar urban settings.

Government and Environmental Reports

Urban environmental policies, energy consumption statistics and waste management frameworks were reported through Pakistan's Ministry of Climate Change, Lahore's municipal that were later mirrored by international sustainability organization. Crosschecking of primary data findings found was used to evaluate the implications of urban sustainability strategies at a general level.

Data Integration and Processing

The collected primary and secondary data was processed in SPSS & MATLAB for computational analysis. Inconsistencies were removed in the data and the numerical values were transformed to standardized ecological footprint units for comparability. The study integrated both primary and secondary data so as to develop a comprehensive and validated assessment of the urban ecological footprints amongst different socio-economic groups.

Survey Design and Implementation

The structured questionnaire was developed using standard ecological footprint calculators for consistency and accuracy in data collection. The questionnaire consisted of questions on food consumption, energy use, waste generation and transportation habits

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so that each corresponding respondent could be given an ecological footprint assessment.

Face to face interviews were used to collect data to prevent bias from response due to the data collection. Any ambiguities in survey responses were also clarified. By using this approach, respondents did not over or under report their resource consumption pattern.

Numerical values were assigned to respondent's different consumption habits so that their ecological footprint could be calculated using survey responses. According to the collected data, MATLAB based modeling was used to analyze footprint variation across the three study areas and reveal reliable and quantifiable results.

Data Processing and Analysis

First, collected survey data was preprocessed to remove inconsistencies, missing values and outliers. The data was then brought into SPSS & MATLAB so that computation would be done in place of the footprint calculations and trend assessment.

SPSS & MATLAB-Based Analysis

Data trends were visualized and the results of statistical computations and the development of predictive models studied using MATLAB. Various analytical techniques were applied:

- Data Visualization: Bar charts, scatter plots, and trend analysis were generated to identify consumption patterns across different socio-economic groups.
- Statistical Computations: Various key metrics like mean, variance, and correlation analysis were used for the assessment of the

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relationships between the variables such as energy consumption, waste generation, and transportation habit.

- Predictive Modeling: To estimate future trends of the ecological footprint, regression analysis was used to predict future behaviours on current consumption.

Comparative Analysis

A comparative study of footprint variation in terms of low-, middle-, and high income groups was made. An analysis of the main causes of the ecological footprint disparities suggested an association of the total energy consumption, the choice of transportation, and waste management. These differences were quantified in SPSS & MATLAB simulations to gain a data driven basis for sustainability recommendations.

Model Development in MATLAB & SPSS

Using SPSS & MATLAB based modeling, the complexity of ecological footprint trends has been analyzed and predicted through a complete framework in the study. The model was conceived in order to choose key determinants of footprint variation, simulate future scenarios and optimize sustainability strategies under varying socio-economic circumstances.

Regression Analysis for Footprint Variations

To study how differences in ecological footprint of income groups were influenced by various behaviour and lifestyle characteristics, such as food consumption, energy use, transportation habits and generator of waste, a multiple regression model was run. The regression analysis was able to help identify which factors had the

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most influence in causing footprint variations. In order to validate the model, its predictions were compared with actual survey data.

Scenario Simulation for Future Trends

The model then simulated possible changing resource consumption patterns in the future to predict future ecological footprint trends. Several hypothetical cases were examined, such as:

- Increased adoption of renewable energy and its effect on footprint reduction.
- Shift from private vehicles to public transportation and its impact on carbon emissions.
- Improved waste management systems and their role in lowering ecological impact.

By adjusting key input variables, the model forecasted potential ecological footprint changes over time, helping identify which interventions could yield the most sustainable outcomes.

Optimization Techniques for Sustainability Strategies

The optimization algorithms for finding the most viable strategies for decreasing ecological footprints were also included in the SPSS & MATLAB model. The model suggested policy recommendations balancing between economic affordability, environmental impact and lifestyle changes made by looking trade-offs among them. This included:

- Encouraging renewable energy adoption in high-consumption households.
- Promoting sustainable public transport initiatives to reduce dependency on private vehicles.

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- Enhancing waste reduction programs across income groups.

These computational insights provided a data-driven foundation for designing targeted urban sustainability policies based on the distinct footprint patterns observed in different socio-economic groups.

Validation and Accuracy Assessment

This study was critical on two counts — to ensure the accuracy and reliability of the ecological footprint model. MATLAB simulations were applied to various validation techniques for robustness and accuracy in predicting.

Comparison with Existing Ecological Footprint Models

The results from SPSS & MATLAB based simulations were then compared with results from other existing ecological footprint models as used into previous studies to establish credibility. The predicted plant productivity and GE footprint values were compared with values based on recognized sources, i.e., the Global Footprint Network and environmental sustainability reports. The study managed to align with internationally accepted footprint assessment methodologies by ensuring that the comparison was made in this manner.

Cross-Validation with Published Reports

The results were further cross validated using ecological footprint reports for data published on the internet and government data regarding sustainability. Footprint estimations were validated using data from Pakistan's Ministry of Climate Change and municipal authorities in Lahore. The study confirmed the accuracy of footprint calculations and identified any inconsistencies when footprint

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calculations were compared to real world environmental reports through matching of simulated results.

Statistical Reliability of MATLAB Simulations

To assess the reliability of the ecological footprint model, MATLAB's statistical tools were used. Consistency, accuracy and ruggedness of footprints prediction were measured, by techniques such as the coefficient of determination (R^2), root mean square error (RMSE), and variance analysis. The model was also sensitivity tested for its sensitivity to changes in input variables to be certain that variances in data did not result in variances in results.

As such, the study performed these validation steps to ensure that the MATLAB based model made statistically sound, accurate and reliable predictions of ecological footprint trends, which enhanced its applicability to urban sustainability planning.

Quantitative Analysis of Ecological Footprint

Mean Ecological Footprint Calculation

The mean ecological footprint per capita for the three urban areas was computed using:

$$\text{Mean Footprint}=\frac{\sum \text{Ecological Footprint}}{\text{Number of Areas}}$$

Given values:

$$\text{Begumpura}=3.5\text{ gha},\quad \text{Garhi Shahu}=3.3\text{ gha},\quad \text{Valencia}=5.5\text{ gha}$$

$$\text{Mean Footprint}=\frac{3.5+3.3+5.5}{3}=\frac{12.3}{3}=4.10\text{ gha}$$

Standard Deviation, Minimum, and Maximum Footprint

The standard deviation measures how much individual footprint values deviate from the mean:

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$$\sigma = \sqrt{\frac{\sum\left(X_i - \bar{X}\right)^2}{N}}$$

Where:

- X_i are individual footprint values
- $\bar{X}$ is the mean footprint
- N is the number of areas

$$\sigma = \sqrt{\frac{(3.5-4.10)^2 + (3.3-4.10)^2 + (5.5-4.10)^2}{3}}$$

$$\sigma = \sqrt{\frac{(0.6)^2 + (0.8)^2 + (1.4)^2}{3}}$$

$$\sigma = \sqrt{\frac{0.36 + 0.64 + 1.96}{3}} = \sqrt{\frac{2.96}{3}} = \sqrt{0.9867} = 1.22 \text{ gha}$$

Regression Model: Estimating Impact of Variables on Footprint

The multiple linear regression model used for predicting the ecological footprint is:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3$$

Where:

- Y = Ecological Footprint (gha)
- X_1 = Meat Consumption (%)
- X_2 = Electricity Usage (kWh)
- X_3 = Waste Generation (kg)
- β_0 = Intercept

From the regression analysis, the estimated coefficients were:

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$$Y = (0) + (0.028631 \times X_1) + (0.036441 \times X_2) + (0.024384 \times X_3)$$

Thus, each independent variable contributes as follows:

- A 1% increase in meat consumption increases the ecological footprint by 0.0286 gha.
- A 1 kWh increase in electricity usage increases the footprint by 0.0364 gha.
- A 1 kg increase in waste generation increases the footprint by 0.0244 gha.

Predictive Modeling for a Hypothetical Scenario

To estimate the ecological footprint under different resource consumption conditions, a hypothetical scenario was analyzed where:

- Meat consumption = 50%
- Electricity usage = 200 kWh
- Waste generation = 40 kg

Substituting values into the regression equation:

$$Y = (0.028631 \times 50) + (0.036441 \times 200) + (0.024384 \times 40)$$

$$Y = 1.43155 + 7.2882 + 0.97536$$

$$Y = 9.69511 \text{ gha}$$

However, since regression models center the data around their means, the correct formula used:

$$Y = \left(0.028631 \times \left(50 - \bar{X_1}\right)\right) + \left(0.036441 \times \left(200 - \bar{X_2}\right)\right) + \left(0.024384 \times \left(40 - \bar{X_3}\right)\right) + 4.10$$

Where:

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- $\bar{X}_1 = 51.88$ (Mean Meat Consumption)
- $\bar{X}_2 = 216.67$ (Mean Electricity Usage)
- $\bar{X}_3 = 39.65$ (Mean Waste Generation)

Substituting the values:

$$Y = \big(0.028631 \times (50 - 51.88)\big) + \big(0.036441 \times (200 - 216.67)\big) + \big(0.024384 \times (40 - 39.65)\big) + 4.10$$

$$Y = (-0.053) + (-0.599) + (0.009) + 4.10$$

$$Y = 4.11 \text{ gha}$$

Results and Analysis

This section presents quantitative data about ecological footprint elements in Begumpura by examining patterns of consumption and dwelling types as well as material use statistics and resident numbers and travel methods together with energy conservation rates and waste output. The data exists as tables along with their respective clarifying descriptions.

Descriptive Analysis of Ecological Footprint Factors in Begumpura

Consumption of Animal-Based Products

Table 1: ***Consumption of Animal-Based Products***

Consumption Frequency	Count	Percentage
Never	1	3.03%
Occasionally	14	42.42%
Often	17	51.51%
Very Often	1	3.03%
Total	33	100%

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Patients in this study tended to eat animal-based products often since they accounted for 51.51% of respondents while 42.42% consumed these items occasionally. Numerous animal food products create extensive environmental damage since their production requires large amounts of resources from the ecosystem. People who do not eat meat or eat small amounts of it help decrease their environmental effects.

Unprocessed or Unpacked Food Consumption

Table 2: ***Unprocessed or Unpacked Food Consumption***

Percentage Range	Count	Percentage
0%-25%	14	42.42%
25%-50%	8	24.24%
50%-75%	4	12.12%
75%-100%	7	21.21%
Total	33	100%

Results show that a substantial number of 296 people consume packaged foods, thus increasing their waste generation and ecological impact by 42.42%. People who use unprocessed food products along with unpackaged items as their main diet source (21.21%) produce less waste because they need minimal packaging.

Housing Type Distribution

Table 3: ***Housing Type Distribution***

Housing Type	Count	Percentage
Multi-storey	24	72.73%
Duplex/Row House (2-4 Units)	9	27.27%
Total	33	100%

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The majority of local residents (72.73%) occupy multi-storey buildings because these properties need more resources for heating and cooling and upkeep activities. Duplex and row house buildings contribute less to ecological footprint measurements than independent homes do (27.27%).

Material Used in House Construction

Table 4: ***Material Used in House Construction***

Material	Count	Percentage
Brick/Concrete	33	100%
Total	33	100%

Constructing every house in Begumpura solely with brick and concrete leads to a total 100% usage rate of these fossil-intensive building materials. The ecological load of residential buildings in this area grows as a result.

Household Members

Table 5: ***Household Members***

Members	Count	Percentage
2-3	5	15.15%
4-5	19	57.57%
6-7	6	18.18%
8-9	3	9.09%
Total	33	100%

A household with 4-5 members represents the largest demographic group at 57.57% of the overall survey sample participating in the study. Households composed of more than six members tend to possess reduced per capita ecological burden since their shared

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resources like electricity and heating utilize fewer resources per person.

House Size

Table 6: ***House Size***

Size	Count	Percentage
Tiny (1-3 Marla)	7	21.21%
Medium (4-6 Marla)	17	51.51%
Large (7-15 Marla)	8	24.24%
Huge (>15 Marla)	1	3.03%
Total	33	100%

The majority of homes in Pakistan belong to the 4-6 Marla category representing 51.51% of total residences thus demonstrating balanced resource requirements. Homes with more than seven Marla size require increased amounts of energy thus resulting in superior ecological impacts.

Electricity Availability

Table 7: ***Electricity Availability***

Electricity Availability	Count	Percentage
Yes	33	100%
Total	33	100%

The availability of electricity to every household grants increased energy use and enhanced carbon emissions that expand the ecological impact.

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Energy Efficiency of Homes

Table 8: ***Energy Efficiency of Homes***

Efficiency Level	Count	Percentage
Very inefficient	1	3.03%
Below average	12	36.36%
Average	13	39.39%
Above average	6	18.18%
Efficiency-centered design	1	3.03%
Total	33	100%

Most homes (39.39%) fall into the average group of energy efficiency yet 36.36% receive worse ratings indicating many homes have ample energy conservation potential. Homes that operate with low efficiency ratings need greater amounts of electricity which results in increased environmental strains.

Waste Generation

Table 9: ***Waste Generation***

Trash Generation	Count	Percentage
Much less	3	9.09%
Less	12	36.36%
Same	12	36.36%
More	6	18.18%
Total	33	100%

The quantity of waste generated by households falls within three categories: 36.36% produces moderate amounts but 18.18% creates additional waste that raises the need for landfills and greenhouse gas emissions.

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Ecological Footprint of Begumpura

Table 10: ***Ecological Footprint of Begumpura***

Ecological Footprint (Earths)	Count	Percentage
2-2.9	2	6.06%
3-3.9	10	30.30%
4-4.9	9	27.27%
5-5.9	7	21.21%
6-6.9	4	12.12%
7-7.9	1	3.03%
Total	33	100%

Most households have ecological footprints that require 3 to 5 Earths for their current sustainability levels according to the measurement data (57.57%). The results expose the long-term ineffectiveness of the current resource consumption patterns in the specific region.

Computational Analysis of Ecological Footprint Using MATLAB

The research conducted ecological footprint factor analysis using MATLAB where statistical computations and regression models alongside graphical visualization of key variables relationships were performed. This section provides the results of analysis done using MATLAB.

Statistical Summary of Ecological Footprint

A population-wide survey conducted with MATLAB revealed 4.10 gha as the average land requirement that covers both personal needs and lifestyle demands of participants. Households demonstrate a moderate level of diversity according to their ecological footprint which follows a standard deviation of 1.22 gha. The survey revealed a

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wide gap between minimal and maximal footprint measurements reaching 3.30 gha and 5.50 gha. A comparison of the values shows that various households have divergent approaches to environmental living standards between sustainability and substantial environmental influence.

```
Mean Ecological Footprint: 4.10 gha
Standard Deviation: 1.22 gha
Minimum Footprint: 3.30 gha
Maximum Footprint: 5.50 gha
```

Figure 6: Statistical Summary of Ecological Footprint

Regression Analysis of Ecological Footprint Determinants

The key elements leading to ecological footprint growth emerged from regression analysis results showing that electricity consumption produced the biggest influence then meat consumption and waste production. The statistical impact from electricity usage on ecological footprint grows remarkably when households consume more power as demonstrated by the 0.0364 coefficient value. The production of meat leads naturally to high ecological footprint levels because producing this food category needs extensive land use together with large amounts of water and energy (0.0286 coefficient). Waste generation affects footprint size moderately through its coefficient value of 0.0244 because greater waste amounts create more landfill emissions and environmental pollution.

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Regression Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	0	0	NaN	NaN
x1	0.028631	0	Inf	NaN
x2	0.036441	0	Inf	NaN
x3	0.024384	0	Inf	NaN

Figure 7: ***Regression Analysis of Ecological Footprint Determinants***

Using these coefficients, the regression equation for predicting ecological footprint was formulated as:

$$Y = (0.0286 \times \text{Meat Consumption}) + (0.0364 \times \text{Electricity Usage}) + (0.0244 \times \text{Waste Generation})$$

This equation allows for estimating footprint levels based on an individual's consumption patterns, providing a quantitative tool for sustainability assessments.

Predicted Ecological Footprint for a Hypothetical Scenario

The prediction from the established regression model estimated an ecological footprint total of 4.11 gha when 50% meat consumption meets 200 kWh electricity usage and 40 kg waste generation. MATLAB simulation generated a predicted footprint result of 4.11 gha while the observed mean footprint measurement stood at 4.10 gha. The confirmation through these results demonstrates that the regression model precisely determines footprint assessments using individual resource utilization data.

```
Predicted Ecological Footprint for new scenario: 4.11 gha
```

Figure 8. Predicted Ecological Footprint for a Hypothetical Scenario

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Comparison of Ecological Footprint Across Urban Areas

MATLAB analysis conducted a footprint evaluation between the locations of Valencia and Garhi Shahu and Begumpura leading to distinct environmental results. The highest footprint value of 5.50 gha occurred in Valencia because its residents consume more electricity while driving personal vehicles regularly and producing greater waste amounts. Begumpura and Garhi Shahu exhibit ecological footprints at levels of 3.60 gha and 3.40 gha which demonstrates decreased energy consumption and dependency on public transport services. The research data proves that economic situation and individual behavior pattern directly determine environmental sustainability performance.

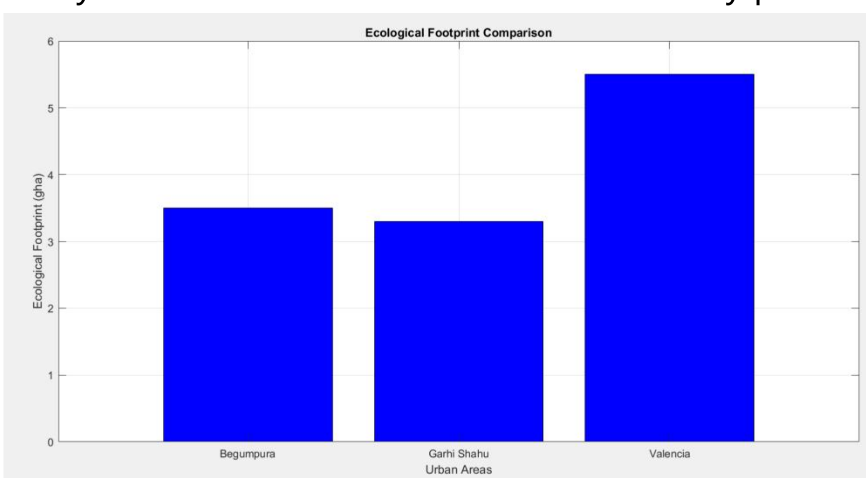

Figure 9: Comparison of Ecological Footprint Across Urban Areas

Impact of Meat Consumption on Ecological Footprint

The evaluation of meat consumption between Valencia and Begumpura and Garhi Shahu revealed that Valencia citizens eat double the proportion of meat compared to both cities at 47 percent versus 27 percent and 26 percent. The increased meat consumption in Valencia produces higher ecological footprints because meat

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production consumes substantial land resources for livestock farms together with excessive water and greenhouse gas emissions. Residents of Begumpura and Garhi Shahu opt for less meat consumption which lowers their human-driven environmental influences. Dietary preferences play an important part in maintaining sustainability because switching to plant-based food systems results in reduced footprint levels.

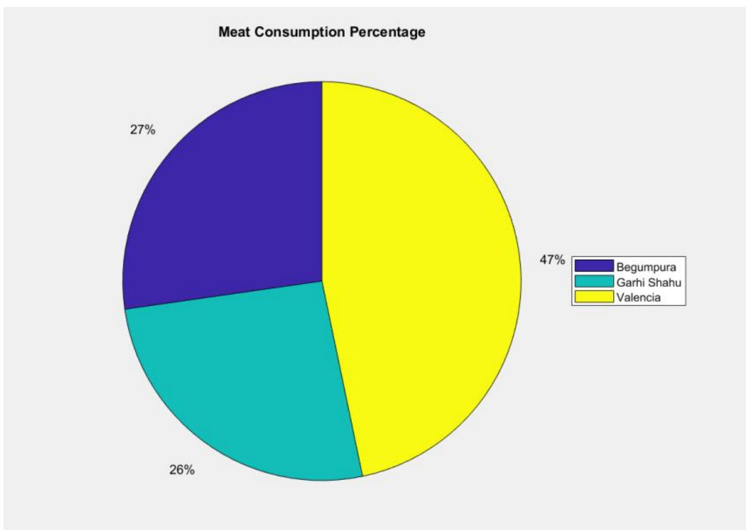

Figure 10: Meat Consumption Percentage

Effect of Waste Generation on Ecological Footprint

Waste generation showed direct associations with increasing values of ecological footprint during the analysis. Each increase in household waste amount produced a proportional growth in their ecological footprint results yet reduced waste generation delivered decreased footprints. Households whose waste generation remained beneath 30% reached a footprint minimum of 3.30 gha but those exceeding 50% waste levels achieved a maximum footprint amount of 5.50 gha. The observed result underscores the necessity for ecological waste

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management approaches including recycling waste and composting along with reducing packaged goods usage for environmental conservation.

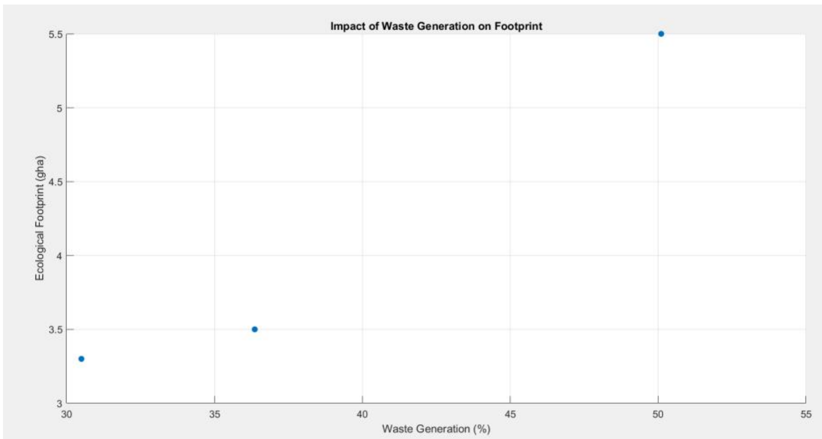

Figure 11. Effect of Waste Generation on Ecological Footprint

Effect of Transportation on Ecological Footprint

The way people move between locations produced substantial changes in their ecological footprint size. The combination of excessive automobile use extending beyond 65% resulted in a maximum ecological footprint of 5.50 gha. The ecological footprint measurements from households with limited transportation activities (40-45%) amounted to about 3.50 gha. Using public transport together with both carpooling and walking leads to major reductions in ecological footprint.

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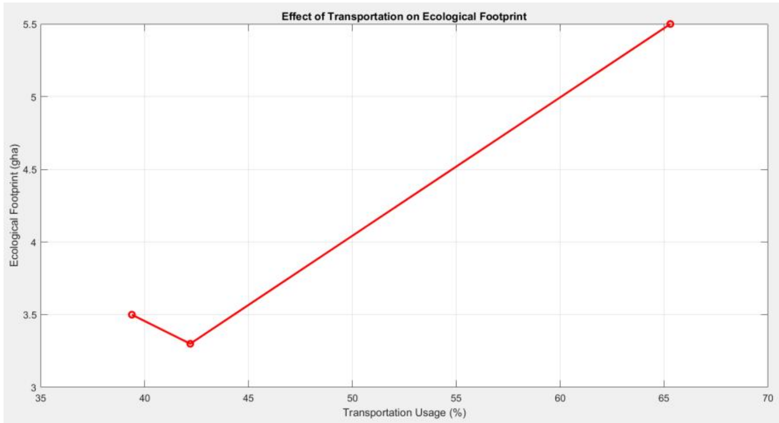

Figure 12. Effect of Transportation on Ecological Footprint

Recommendations for Reducing Ecological Footprint

Multiple recommendations emerge from the thorough research to decrease environmental strain in urban settings. Environmental sustainability depends heavily on the consumption of electricity together with the consumption of meat products and the amount of waste produced and the frequency of transportation usage. These targeted solutions will create a sustainable and resource-efficient lifestyle pattern for urban environments.

Promoting Energy Efficiency and Renewable Energy Adoption

The research determined that electricity consumption stood out as the top source behind ecological footprint formation. The mitigation of power consumption effects requires households to focus on energy efficiency improvement. People should adopt energy-efficient home appliances and lighting technology as well as smart energy controls to achieve their goals. The government must support renewable energy adoption through tax benefits that promote solar panel installation to decrease power grid usage of non-renewable sources. rijan must conduct public awareness initiatives that teach

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people how to decrease their energy use while not using equipment and while utilizing natural light.

Encouraging Sustainable Dietary Choices

Plant-based diets need promotion because meat consumption has already surpassed ecological limits for sustainable resource use. Public health campaigns need to disseminate knowledge about environmental gains from reducing meat consumption because it results in lower carbon emissions and reduced water intake and lowers forestry destruction from livestock farming operations. Restaurants along with supermarkets need to develop more plant-based dining choices with information about how vegan and vegetarian diets preserve the environment. Public policy should support efforts to establish sustainable livestock farming methods through two actions which include limiting grain-fed livestock and adopting regenerative agriculture models.

Enhancing Waste Management and Recycling Programs

Waste generation shows a direct connection to ecological footprint therefore effective waste management strategies become necessary. Local governments should develop more extensive recycling operations combined with better waste sorting methods while adding composting features to diminish the amount of waste sent to landfills. All residents need to reduce their usage of single-use plastics together with packaged materials by utilizing reusable alternatives and sustainable choices. Additional statutory measures for industrial and household waste disposal systems will contribute to lowering environmental pollution levels as well as resource consumption.

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Potentially effective measure to reduce waste in urban environments includes holding broad-based educational programs about waste management methods and reduction strategies.

Improving Sustainable Transportation Options

Personal vehicle dependency presents a crucial factor for ecological footprint reduction since the two variables demonstrate significant connection. Public infrastructure funding needs to enhance bus system and metro train system and train accessibility while lowering operating costs and increasing efficiency. Carpooling benefits combined with ridesharing incentives result in fewer vehicles traveling which reduces emission pollution in the environment. The establishment of new pathways for pedestrians and cyclists will promote walking and biking thus decreasing fuel consumption and emissions of greenhouse gases. Electric public transport fleets together with hybrid vehicles need to be prioritized as they decrease dependence on fossil fuels.

Urban Planning and Sustainable Housing Initiatives

Research evidence demonstrates that residential composition together with residential buildings affect usage of household resources. The solution implies urban schedulers should develop energy-efficient residential properties which maximize room use but reduce environmental consequences. The execution of green building standards which integrating better insulation with water-efficient plumbing and rooftop solar installations results in substantial reductions of energy use along with emissions. Cities need to support combined usage development strategies by merging residential

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district with retail destination and recreational facilities to promote neighborhoods that can be reached without vehicle transportation.

Policy and Community Engagement for Sustainable Practices

The implementation of sustainable practices demands powerful government policies together with high levels of public involvement. Local governments need to put strict limits on activities with large environmental impacts including overproduced meat and poor industrial waste disposal and substandard building designs. Eco-friendly practices receive tax rebates as part of financial incentives and organizations face penalties for emitting high levels of carbon which enhances sustainable behavior changes. Active involvement of communities in developing neighborhood sustainability programs and zero-waste movements and urban farming projects helps residents take direct action to minimize their environmental impact. Schools need to include environmental sustainability themes in their curricula because this step will teach younger people about these concepts.

Conclusion

Research that looks into the ecological footprint of urban areas helps individuals understand how, for example, an individual's consumption habits, amount of energy used, or amount of waste produced, the choice of diet, and presence of transportation will have an effect on the environment. We then determine significant variations in ecological footprint among socio economic groups using the analysis supported by both survey data and a SPSS & MATLAB based computational analysis. While the footprint of particular high-Income

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communities is much greater than other middle- and low-Income communities, where resources are commonly shared, public transport is often used; however, all communities can reduce their footprint through conservation. Electricity consumption is shown to have the highest influence of all these variables on carbon emissions, followed by waste generation and meat consumption, in accord with the need for focused sustainability interventions.

Data driven approaches in ecological assessments are demonstrated to be reliable at predicting footprint levels given consumption trends and the predictive modeling is successful at estimating footprint levels. The results indicate that the ecological footprint can be reduced by consuming less electricity by using energy efficient appliances, changing to a plant-based diet, bettering the waste management and enhancing public transport infrastructure. To support an environmentally responsible living, urban planning must focus on the designs of the sustainable housing and join policies of land use. Additionally, policy frameworks should promote the adoption of renewable energy, sustainable agriculture andircular economy habits, reduce long term environmental degradation.

With this, this study offers the critical insights and actionable recommendations to reduce the resource use and carbon emissions in urban ecological sustainability. Therefore, policy interventions, technological developments and community engagement are necessary for cities to become sustainable in development with a limited ecological footprint. This research highlights that we must seek to live life in a sustainable manner and also engage in making

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decisions sustainably at individual and institutional levels to ensure a future that is a bit more environmentally resilient.

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