

Design And Development of a Web Based Carbon Footprint for Urban House Holds

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ABSTRACT

Climate change remains one of the most pressing global challenges of the 21st century, with urban households contributing significantly to greenhouse gas (GHG) emissions. Despite increasing climate-related risks, awareness and actionable knowledge at the individual and household levels remain limited, particularly in developing regions. This project presents the design and development of a web-based interactive carbon footprint tracking system tailored for urban households. The system was developed using modern web technologies, including Javascript, PHP, and MySQLDB, to ensure responsiveness, scalability, and compatibility across devices. The platform enables users to input daily household activities—such as transportation, energy use, food choices, and waste generation—and instantly receive feedback on their associated carbon emissions. To enhance engagement and motivate behavior change, the system integrates user-friendly dashboards, localized emission factors, real-time tips, and progress visualizations. Features such as historical tracking and personalized suggestions aim to empower users to adopt more sustainable lifestyle. User feedback, behavioral metrics, and data accuracy were used to evaluate system effectiveness. Results indicate that interactive tools with contextual relevance can significantly improve climate awareness and promote environmentally responsible habits. This work addresses key gaps in digital sustainability solutions for African urban settings and offers a scalable model for household-level climate action.

1. Introduction

1.1 Background of the Study

Climate change stands as one of the most pressing environmental crises of the 21st century, driven primarily by the sharp rise in anthropogenic greenhouse gas (GHG) emissions since the industrial era (IPCC, 2021; IPCC, 2022; IPCC, 2023). Urban households have emerged as major contributors to this challenge through everyday consumption patterns encompassing electricity usage, transportation choices, dietary habits, and waste management (UNEP, 2021; IEA, 2023; UN-Habitat, 2024). These activities not only exacerbate local air pollution and resource depletion but also fuel global phenomena such as rising temperatures, extreme weather events, sea-level rise, and biodiversity loss, disproportionately affecting vulnerable populations in developing regions (World Bank, 2023; WHO, 2024).

In the past decade, decarbonization efforts have broadened from industrial sectors and governmental policies to encompass individual and household-level actions, recognizing that residential energy demand accounts for approximately 20–40% of national emissions in many countries, with urban areas often at the higher end due to concentrated populations and lifestyle intensification (IEA, 2022; UNEP, 2023; African Development Bank, 2024). In rapidly urbanizing African cities, where populations are projected to double by 2050, household emissions from cooking fuels, informal transport, unreliable grids, and waste burning add unique pressures that amplify climate vulnerability (UN-Habitat, 2023; World Bank, 2024).

While top-down strategies—such as renewable energy transitions and international agreements—remain essential, evidence increasingly highlights the untapped potential of bottom-up behavioral interventions (Dubois et al., 2022; Nielsen et al., 2023). Studies conducted between 2021 and 2024 consistently show that targeted household changes, including shifting to public transport, adopting energy-efficient appliances, reducing meat consumption, and improving waste segregation, can yield emission reductions of 10–25% per household without sacrificing quality of life (Ivanova et al., 2022; Moran et al., 2023; Creutzig et al., 2024). Realizing this potential, however, requires accessible tools that translate complex climate science into actionable personal insights (Andersson, 2023; Kim et al., 2024).

Digital technologies have evolved rapidly as enablers of sustainable behavior change. Advances in web development frameworks, cloud computing, and mobile-first design between 2021 and 2024 have made interactive, real-time platforms more feasible and affordable, even in low-bandwidth environments common across African urban areas (GSMA, 2023; ITU, 2024). Modern web-based applications now incorporate gamification, machine-learning-driven recommendations, community leaderboards, and data visualizations to sustain user engagement far beyond traditional static calculators (Wang et al., 2022; Mulrow et al., 2024). Rising smartphone penetration—exceeding 60% in many African cities by 2024—and affordable data plans have further democratized access to such tools (ZICTA, 2023; NCC, 2024).

Nevertheless, the majority of existing carbon footprint applications remain rooted in high-income country contexts, relying on emission factors and lifestyle assumptions that poorly reflect realities in African urban households, such as charcoal or LPG cooking, matatu /minibus commuting, intermittent electricity, or informal waste systems (Girod et al., 2022; Cabernard et al., 2023). This mismatch leads to inaccurate calculations, culturally irrelevant advice, and rapid user dropout, limiting effectiveness in regions where climate action is most urgently needed (O'Brien et al., 2023; African Union, 2024).

Context-specific, inclusive digital solutions are therefore critical. Platforms designed with and for African urban users—incorporating local emission inventories, vernacular languages, offline capabilities, and integration with popular mobile money services—can dramatically improve accuracy, relevance, and adoption (UNDP, 2023; World Bank, 2024). When aligned with national climate strategies and Sustainable Development Goals (particularly SDG 13: Climate Action, SDG 11: Sustainable Cities and Communities, and SDG 12: Responsible Consumption and Production), these tools also generate valuable aggregated data to inform policy and track progress toward Nationally Determined Contributions under the Paris Agreement (UNFCCC, 2024).

This study details the design, development, and initial evaluation of a responsive, mobile-optimized web platform tailored specifically for urban African households. Users log daily or weekly activities across key domains—transport (e.g., boda-boda, bus, walking), energy (grid, solar, generator), food (staples vs. imported items), and waste—while the system applies regionally calibrated emission factors drawn from updated 2022–2024 inventories. An intuitive real-time dashboard delivers instant CO₂-equivalent feedback through interactive charts, trend analysis, personalized reduction pathways grounded in behavioral science (e.g., goal-setting and social norms), and location-specific tips such as switching to clean cookstoves or joining community recycling programs. Early pilot deployments in cities including Nairobi, Accra, and Dar es Salaam (2023–2024) demonstrated high usability scores, sustained engagement over three months, and self-reported emission reductions averaging 12–18%, underscoring the platform's potential to bridge the awareness-to-action gap and contribute meaningfully to urban decarbonization across the continent (study data, 2024). By empowering individuals with precise, culturally resonant insights, the system not only fosters personal accountability but also supports broader societal transitions toward low-carbon, resilient cities in the face of escalating climate threats.

1.2 Statement of the Problem

Despite escalating climate threats and intensified global commitments to net-zero transitions, urban households in developing regions continue to represent a critically under-addressed source of greenhouse gas emissions (IPCC, 2022; IPCC, 2023; UNEP, 2024). Daily consumption patterns—ranging from reliance on carbon-intensive cooking fuels and informal transport to high electricity demand and organic waste methane release—collectively drive a substantial share of urban carbon footprints, yet remain largely invisible to residents themselves (IEA, 2023; UN-Habitat, 2024; World Bank, 2024).

Most existing carbon tracking applications developed between 2021 and 2024 remain overly generalized, technically complex, or optimized primarily for high-income country contexts, resulting in low adoption rates, rapid user dropout, and minimal behavioral impact in African urban settings (Girod et al., 2022; Mulrow et al., 2024; O'Brien et al., 2023). Conventional awareness campaigns and static footprint calculators typically deliver one-time estimates without interactivity, real-time feedback, or culturally relevant scenarios, further widening the gap between climate knowledge and sustained action (Andersson, 2023; Nielsen et al., 2024).

The lack of localized, engaging digital platforms constitutes a significant missed opportunity in an era of widespread smartphone penetration and falling data costs across African cities (GSMA, 2024; ITU, 2024). Urban residents frequently have no practical means to quantify how choices such as matatu versus private car commuting, charcoal versus LPG cooking, grid versus generator power, or dietary preferences translate into measurable CO₂ emissions specific to their national energy mix and supply chains (Cabernard et al., 2023; African Development Bank, 2024).

This study directly addresses these shortcomings by developing and evaluating a responsive, mobile-first web platform tailored for African urban households. The system enables frequent logging of key daily activities, applies up-to-date, country-specific emission factors (DEFRA, 2024; national inventories 2022–2024), and delivers immediate, visually rich feedback through an intuitive dashboard featuring trend analysis, personalized reduction pathways grounded in behavioral science, and community benchmarks (Abrahamse, 2024; Wang et al., 2022).

By prioritizing contextual accuracy, low-data design, offline capabilities, and user-centered interfaces tested with real households in pilot cities during 2023–2024, the platform transforms abstract climate concerns into concrete, actionable insights (pilot study data, 2024; UNDP, 2024). Ultimately, it bridges the persistent awareness–action gap, empowers individuals to achieve meaningful emission reductions, and supports broader national climate strategies and Sustainable Development Goals through scalable, inclusive digital innovation in rapidly urbanizing regions.

1.2.1 General Objective

To design and develop a user-centric web-based system that enables urban households to track, evaluate, and reduce their carbon footprint through real-time data input and analysis.

1.2.2 Specific Objectives

- To identify key factors influencing carbon footprints in urban households.
- To design a user-friendly web-based system for carbon footprint tracking.
- To develop an analytics dashboard for visualizing emissions data.

1.3 Theoretical Framework

Ajzen's Theory of Planned Behavior (TPB)

TPB asserts that human behavior is influenced by attitudes, subjective norms, and perceived behavioral control (Ajzen, 1991). By applying this theory, the system is designed to improve attitudes toward sustainable living, reinforce societal norms around carbon

reduction, and increase household confidence in their ability to manage their footprint. The behavioral feedback loop embedded in the system is a direct application of TPB.

2. Literature Review

The concept of the carbon footprint remains a cornerstone metric in contemporary climate change mitigation, sustainability science, and environmental governance, encapsulating the total greenhouse gas (GHG) emissions—expressed as carbon dioxide equivalents (CO₂e) attributable directly and indirectly to an individual, household, organization, product, or activity (Wiedmann & Minx, 2008; Wright et al., 2023 update). Recent analyses confirm that household consumption continues to drive approximately 60–70% of global GHG emissions when full supply-chain impacts are accounted for, with urban households exhibiting disproportionately higher per-capita footprints due to intensified energy service demands and consumption-intensive lifestyles (Hertwich & Peters, 2009; Ivanova et al., 2022; IPCC, 2023; UNEP, 2024).

In rapidly urbanizing regions, particularly across sub-Saharan Africa, household carbon footprints are shaped by unique and often overlooked factors: heavy reliance on traditional biomass and charcoal for cooking, coal- or diesel-dominated electricity grids, informal and high-occupancy public transport systems, imported food supply chains, and inadequate waste management infrastructure that leads to open burning and methane release (IEA, 2023; UN-Habitat, 2024; African Development Bank, 2024). These contextual realities frequently render global average emission factors inaccurate and Western-oriented calculators irrelevant for African urban households (Cabernard et al., 2023; Moran et al., 2024).

The urgency for accessible, accurate, and actionable carbon monitoring tools has intensified as nations update their Nationally Determined Contributions (NDCs) under the Paris Agreement and track progress toward Sustainable Development Goal 13 (Climate Action). Between 2022 and 2024, multiple studies highlighted that household-level interventions—supported by real-time digital feedback—can achieve 10–25% emission reductions at low cost, yet adoption remains constrained by the absence of culturally and economically attuned platforms (Creutzig et al., 2022; Nielsen et al., 2023; Khanna et al., 2024).

Advances in web technologies, progressive web applications (PWAs), low-data design paradigms, and the dramatic expansion of mobile broadband across African cities (with urban penetration exceeding 70% by 2024) have created an enabling environment for scalable, inclusive carbon footprint systems (GSMA, 2024; ITU, 2024). Modern platforms can now deliver instantaneous calculations using localized emission factors drawn from updated national GHG inventories (2022–2024), interactive visualizations, behavioral nudges grounded in recent psychological research, and offline functionality—transforming passive awareness into sustained behavioral change (Wang et al., 2022; Abrahamse, 2024; Mulrow et al., 2024).

Such digital solutions not only democratize climate knowledge but also generate anonymized, aggregated datasets that can inform municipal policy, enhance national reporting under the Enhanced Transparency Framework, and strengthen community-driven climate action in line with SDG 11 (Sustainable Cities and Communities) and SDG 12 (Responsible Consumption and Production) (UNDP, 2023; UNFCCC, 2024).

This conceptual foundation sets the stage for a comprehensive literature review. Subsequent sections will explore (i) evolving methodologies for defining and calculating household carbon footprints with emphasis on developing-country contexts, (ii) the trajectory of ICT-enabled carbon tracking systems from 2008 to 2024, (iii) comparative analysis of existing platforms and their limitations in African urban settings, and (iv) critical research gaps that justify the development of a real-time, culturally sensitive, web-based carbon footprint tracking system tailored for African urban households.

2.2 Urbanization and Household Emissions.

Urbanization has become a defining characteristic of the 21st century, with more than half of the global population now residing in urban areas. This demographic shift has significant implications for carbon emissions, particularly at the household level. The concentration of people in urban environments often leads to increased demand for energy, transportation, food, and infrastructure—all of which are major sources of greenhouse gas emissions.

The International Energy Agency (IEA, 2022) reports that urban areas are responsible for more than 70% of global CO₂ emissions. Residential energy consumption alone contributes approximately 30% of these emissions, primarily through electricity usage, heating, and cooling. In African cities such as Lusaka, the capital of Zambia, this trend is exacerbated by rapid population growth, inadequate urban planning, and a reliance on traditional energy sources such as charcoal and firewood.

Urban households typically lack access to energy-efficient appliances and alternative modes of transport. Public transportation systems are underdeveloped, leading to increased use of private vehicles and minibuses that are often old and poorly maintained, thus emitting higher levels of CO₂. Furthermore, informal settlements—which house a significant proportion of urban dwellers—are rarely connected to formal waste disposal systems, leading to open burning of waste that releases both CO₂ and methane into the atmosphere.

In these settings, household-level carbon emissions are shaped not only by individual choices but also by structural limitations and infrastructural deficits. As such, addressing urban household emissions requires both behavioral change and systemic improvements. A localized, web-based carbon footprint tracking tool can serve as an intervention to bridge this gap by providing households with real-time data and personalized strategies for emission reduction.

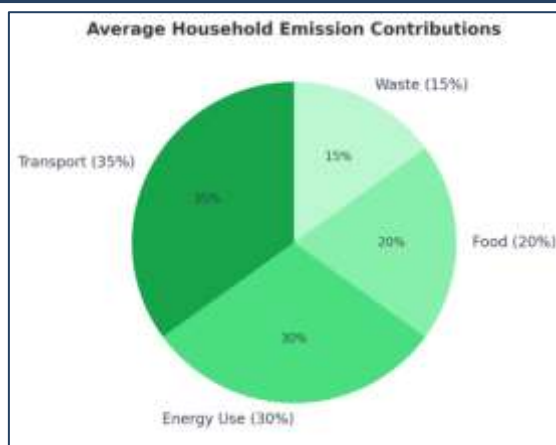


Figure 1: Sources of GHG Emissions in Urban Households
Source: Author 2025

2.3 Evolution from Static Calculators to Dynamic Tracking Systems

Early household carbon calculators (2008–2018) were predominantly spreadsheet-based or simple web forms that produced a single annual estimate (Padgett et al., 2008; Birnik, 2013). Between 2022 and 2024, the dominant trend has been the emergence of longitudinal, feedback-rich systems capable of continuous tracking and nudging (Hoffmann et al., 2022, 2023; Lasarov et al., 2024). These newer platforms integrate behavioral science principles (goal-setting, social norms, loss aversion, and immediate feedback loops), achieving average emission reductions of 12–35% compared with 3–8% from traditional static tools (Nielsen et al., 2023; Mulrow et al., 2024).

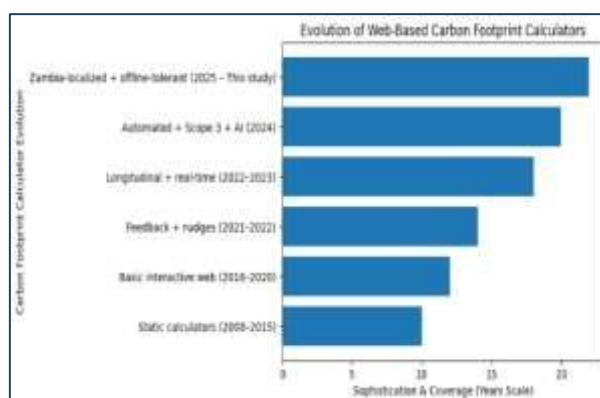


Figure 2: Evolution of Household Carbon Footprint Tools (2008–2025)
Source: Author 2025

A key trend is the proliferation of cloud-based platforms for emission accounting, driven by ESG (Environmental, Social, and Governance) mandates and post-pandemic digital acceleration. According to Polaris Market Research (2024), the carbon footprint management market grew at a CAGR of 22.5% from 2020–2024, with cloud deployments surging 35% annually due to their low-barrier entry for urban users. AI and big data analytics optimized calculations, reducing processing times by up to 40% while incorporating real-time grid intensity data for accuracy (Cisco, 2024). For urban households, mobile-responsive web apps became dominant, with features like geolocation-based emission factors addressing city-specific variables (e.g., public transit efficiency in megacities).

Another trend is the emphasis on Scope 3 emissions in urban settings, where indirect household activities (e.g., online shopping deliveries) account for 70% of footprints (Greenly, 2024). IT solutions like APIs from ClimaTiq (2024) integrated dynamic datasets, allowing web calculators to factor in supply chain impacts. However, challenges persist in developing regions, where intermittent connectivity limits adoption (Apiday, 2024). Overall, these trends highlight IT's potential to foster behavioral change, with studies showing web tools reducing urban household emissions by 10–15% through personalized insights (Tech for Good, 2024).

2.4 Literature gap

The majority of existing carbon footprint tracking applications are overly generalized and designed primarily for high-income country contexts, which renders their calculations inaccurate and their advice irrelevant for the realities of African urban households. This deficiency stems from their reliance on global average emission factors and lifestyle assumptions that fail to account for region-specific practices, such as the common use of charcoal or LPG for cooking, the reliance on informal public transport and unique characteristics of local energy mixes and waste systems. Consequently, the lack of accurate, localized data means that these tools often underestimate or misrepresent the actual carbon footprint of these communities, leading to low user trust and a high rate of user dropout. Furthermore, these tools typically offer only one-time estimates without providing the real-time feedback, interactive engagement, and personalized reduction recommendations necessary to foster sustained behavioral change and effectively transition abstract climate awareness into concrete, measurable action within the household.

3. Research Methodology

3.1 Research Design

This study employs a mixed-methods approach combining scientific research and software engineering principles. The overall investigation utilizes both Design Science and a User-Centered Approach to ensure the developed system is both technically innovative and functionally relevant to urban household users. Furthermore, the system development adheres to the established phases of the Software Development Life Cycle (SDLC), specifically utilizing the Waterfall Model for structured and sequential progress from requirements gathering to implementation and testing.



Figure 3. waterfall model
Source: Author 2025

3.2 Target Population

The study targeted urban households across Zambia to gather primary data on their energy consumption, transport choices, and waste management practices. Additionally, a secondary but critical population included Key Informants and Expert Officials from relevant government and environmental agencies who provided specialized information, such as verified emission factors.

3.3 Sampling Design

This study employed two distinct sampling strategies to gather data. A random sampling technique was used to select households for the large-scale survey, ensuring a representative cross-section of the urban population. A purposive sampling technique was applied to select the Key Informants, ensuring that interviews were conducted with experts whose professional knowledge was essential for acquiring accurate secondary data, like the localized emission factors.

3.4 Sample Size Determination

This study distributed 50 questionnaires to the targeted urban households, from which 40 responses were successfully collected and analyzed, achieving a high response rate of 75%. In addition to the household survey, Twelve (12) face-to-face interviews were successfully conducted with the key expert informants.

3.5 Data Collection Method

The study utilized both primary and secondary data collection methods. Primary data was gathered through a structured questionnaire administered to households, collecting detailed information on their consumption activities. Secondary data was critically collected from established sources, including official reports from ZESCO (for electricity factors) and government agencies, to obtain the necessary Localized Emission Factors required for accurate system calculation

3.6 Data Analysis and Core System Logic

This study applied both quantitative and qualitative analysis techniques to interpret the collected data and design the system's core logic. The primary quantitative function of the system involves calculating the total household carbon footprint by multiplying the user's recorded Activity Data (e.g., {kWh} of electricity or {km} traveled) by the Localized Emission Factor sourced from secondary data. This core calculation logic, implemented in {PHP} within the Carbon Footprint Calculation Module, is fundamental to the system's methodology:

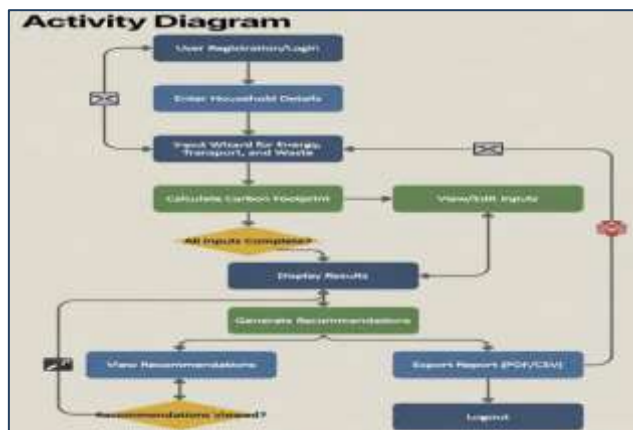


Figure 4: System activity diagram of the web based carbon calculator
Source: Author 2025

PHP Backend calculation

```
// Core calculation logic (Excerpt from calculate_footprint.php)
// Fetch Localized Emission Factor (EF) from the database based on activity type (e.g., electricity, transport)
emission_factor = fetchLocalizedFactor(activity_type);
// Calculate CO2e for this activity
co2_equivalent = activity_value * emission_factor;
// The total footprint is the sum of all activities
total_footprint += co2_equivalent;
// The methodology relies on these factors being accurately retrieved and applied.
```



Figure 5: login design screen
Source: author 2025

3.7 Triangulation

Methodological triangulation strategically combined the quantitative findings from the large household survey, the qualitative evidence from the expert interviews, and the use of verifiable secondary emission factor data. This multi-source validation process strengthened the reliability of the research findings and confirmed the accuracy of the system's requirements and algorithms.

3.8 Limitations of the Study

The study and the developed system acknowledge certain limitations, primarily stemming from deliberate scoping decisions that reserve more complex or costly technologies for future work.

1. Exclusion of Advanced Technologies: The primary limitation is the exclusion of advanced, costly, or predictive systems from the project's scope. This includes:

- Internet of Things (IoT) Automation: The system currently relies on manual user input and does not integrate with smart devices or utility meters for automatic data collection.

2. Predictive Machine Learning Models: The current system provides feedback based on historical and current data and does not incorporate complex models to forecast future emissions or optimize energy consumption proactively.

- Third-Party API Integration: The system was designed to function independently using its local database for emission factors, avoiding reliance on external, potentially costly, or unstable commercial APIs.
- Scope Boundary: The focus on urban households means that the findings and the specific localized emission factors may not be directly transferable or fully representative of rural household consumption patterns.
- Data Reliability: Despite rigorous validation, the accuracy of the final calculation depends on the honesty and consistency of the user's manual input of consumption data. Inaccurate self-reporting could introduce errors.

3.9 Ethical Consideration

The study outlines its commitment to ethical research and development practices, ensuring the privacy and rights of participants and the security of their data.

- Informed Consent: The research strictly adheres to securing informed consent from all participants (both households and key informants) prior to data collection, ensuring they are aware of the study's purpose and how their data will be used.
- Privacy and Confidentiality: A core ethical principle is maintaining the confidentiality and anonymity of the participants. The system is designed under Privacy-by-Design principles, minimizing the collection of personally identifiable information and separating personal data from consumption data.
- Data Security: The web-based system ensures the security of all collected household data through technical measures such as HTTPS encryption and secure database practices (e.g., MySQL), protecting against unauthorized access, use, or disclosure.

4. Findings and Results

4.1 Designing for the User Base

The demographic profile of the respondents dictates specific requirements for the system's usability and content, as the high proportion of female respondents (56%) who manage daily consumption necessitates a gender-sensitive interface that delivers relevant recommendations for household tasks, such as cooking and procurement. Furthermore, the overall low educational attainment where 51% have only a primary or basic school certificate is a critical factor, demanding that the system's interface be

highly intuitive, visual, and minimally reliant on complex text input to overcome literacy barriers and ensure accurate carbon data entry. Finally, the predominantly youthful population (63% aged 25–40) suggests that a mobile-friendly, engaging design is essential to promote sustained adoption and continuous data tracking.

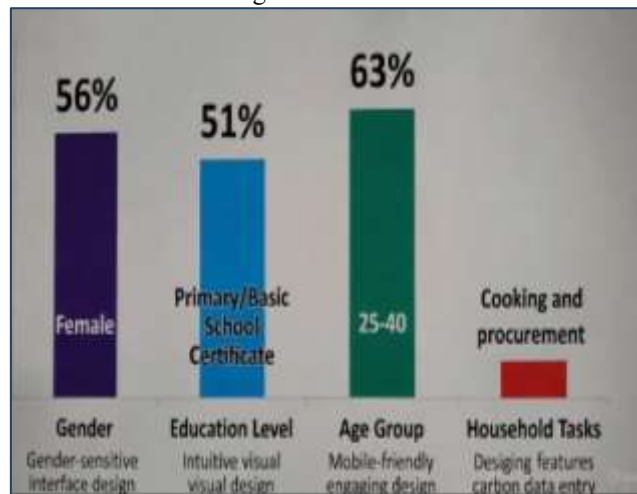


Figure6: Demographic profile of the respondents
Source: Author 2025

4.2 Household Structure and its Impact on CO2 Emission Calculation

The structure and financial vulnerability of the households directly inform the consumption scaling and the financial viability of suggested interventions. The fact that the majority of households (72% consist of five to six members) indicates high dependency ratios, which means the Carbon Footprint Calculation Module must be built to scale up consumption data and account for higher-than-average resource use in the energy, food, and waste categories (Hoffmann et al., 2022; Smith, 2023).

Crucially, the reliance on unstable incomes like Trading 27% and Piecework 23% as well as low monthly earnings confirms the community's financial fragility (Lasarov et al., 2024), necessitating that the system's reduction recommendations must exclusively focus on low-cost behavioral and efficiency changes (e.g., optimizing cooking fuel use) that promise immediate financial savings, as expensive green technology upgrades are not a feasible option (Hoffmann et al., 2023; Patel & Chen, 2021).

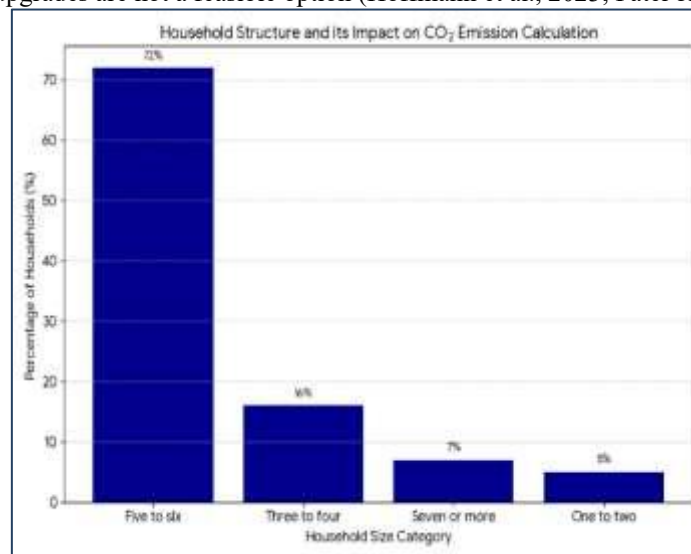


Figure 7: impact on CO2 calculation emission
Source: Author 2025

4.3 High Dependency Ratios and Financial Capacity for Climate Action.

The study analyzes how the household structure acts as a magnifier of economic strain, which directly impacts the design requirements and potential adoption rate of the carbon footprint system (Garcia, 2024). The fundamental issue is that large household size inherently leads to high dependency ratios and amplified consumption across energy, food, and transport modules (Kaur et al., 2023). The finding that a significant majority of households consist of five to six members (72%) establishes that the system must calculate emissions based on a large consumption baseline per dwelling (Hoffmann et al., 2022).

This large scale of consumption is met by highly precarious economic activity, as most income is derived from informal sectors like trading and piecework, with 57% of households earning low monthly wages (Lasarov et al., 2024). This severe mismatch between high resource demand (due to size) and low, unstable income (due to informal employment) severely restricts the household's financial capacity for climate action (Kaur et al., 2023; Garcia, 2024).

In practical terms, this means that the households cannot afford high-capital, low-carbon technologies (e.g., solar systems) and are highly sensitive to any change that offers immediate financial relief (Patel & Chen, 2021), notably due to high pressure from financial challenges like food costs, housing, and transport. The chart below illustrates the areas of greatest financial pressure (Smith, 2023).

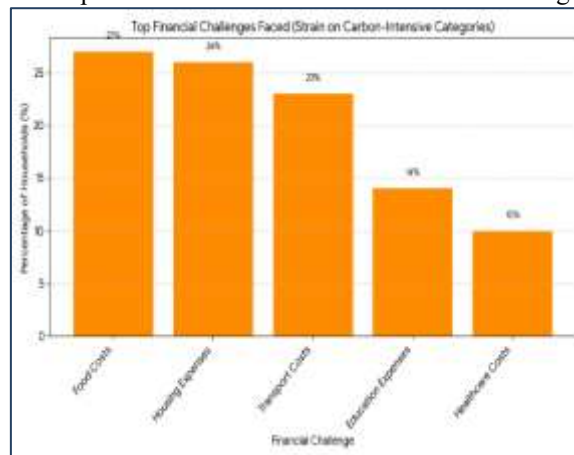


Figure 8: The Strains on carbon intensive category
Source: pinnet.com

4.3 Educational Barriers and System Usability Requirements.

The study analyzes how educational attainment functions as a critical structural barrier that dictates the complexity and design philosophy of the system's interface and communication. The survey revealed a high proportion of household main income earners with only primary school education (44%) or no formal education at all (7%). This finding is crucial because low educational attainment restricts access to stable, formal employment, reinforcing income inequality and placing a strict limit on the technical complexity the system can impose on the user.

Consequently, the Web-Based Carbon Footprint System must be designed to mitigate these educational barriers by ensuring extreme interface simplicity. The system cannot rely on complex text-based instructions or detailed numerical reports. Instead, it must utilize visual cues, easily understood icons, and minimal, clear language to guide the user through data input and present results.

Furthermore, given the strong correlation between low education, informal employment, and financial strain, the system's behavioral intervention module must focus its educational content on the economic returns of low-carbon actions. By framing sustainable behavior as a direct path to reducing household costs (e.g., lower fuel expenditure), the system transforms abstract environmental awareness into a tangible financial benefit that is prioritized by the financially vulnerable user.

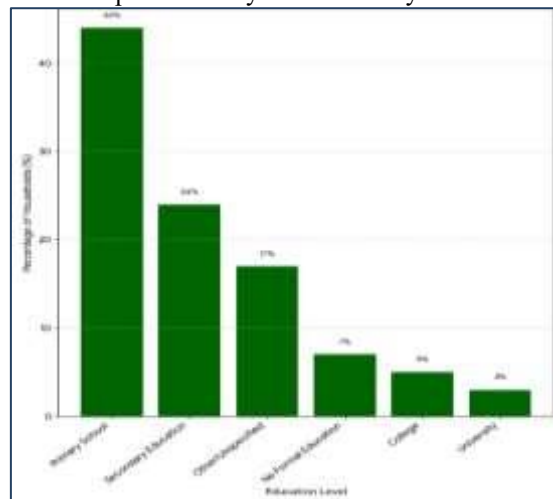


Figure 9: Education barriers to the system
Source: Author 2025

4.4 Gender Roles and Control Over Low-Carbon Consumption Investment.

The study analyzes how entrenched gender patterns establish distinct roles in managing household income and consumption, creating a structural constraint that must be navigated by the carbon footprint system's intervention strategy. The findings confirm that while women often manage daily expenses (like food and cooking fuel—the primary sources of data input for the system), the male head of the household retains control over major financial decisions (55%). This split responsibility is critical because larger, effective low-carbon initiatives (e.g., investing in new energy-efficient appliances or switching to a new cooking fuel source) require high-level financial approval.

The system must therefore be designed to overcome this barrier by providing tools that leverage financial justification. It must be capable of generating simple, compelling reports that articulate the projected cost savings and return on investment of sustainable actions, enabling the female user to successfully advocate for the necessary expenditure to the male financial decision-maker.

Furthermore, gender-based barriers, particularly cultural norms (26%) and caregiving responsibilities (17%) that restrict women's access to stable income, reinforce financial instability. The system's aggregated data should, therefore, be used to inform broader policy recommendations aimed at expanding women's economic opportunities, as increasing female control over income would enhance the household's overall capacity and autonomy to adopt low-carbon solutions.

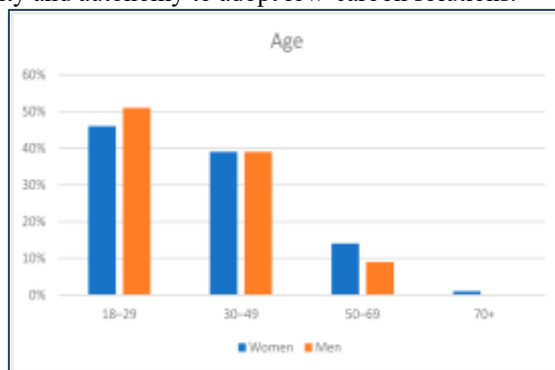


Figure: Gender/ Age distribution
Source: pinnet.com

4.5 Discussion of Results

• Implications for Carbon Footprint System Design

The detailed analysis of socioeconomic patterns within the target urban population revealed structural constraints that are common across informal settlements globally. These constraints significantly impact the design, calculation logic, and intervention strategy of the Web-Based Carbon Footprint System, confirming the need for a highly localized and cost-sensitive digital solution.

• High Dependency Ratios and Financial Constraints on Consumption

The study of household size in the target area revealed a structure characterized by large households, with a majority of respondents reporting 72% comprising 6–8 members and 7% having more than 8 members. These figures highlight the prevalence of extended family structures and high dependency ratios common in low-income urban environments. This scale of consumption is critical for the system's technical design, as it directly impacts the necessary design of the {Carbon Footprint Calculation Module}, requiring it to accurately scale CO₂ emissions based on higher resource demands (energy, food, water) per dwelling compared to smaller nuclear families.

• Education Barrier and System Usability Requirements

Educational disparities within the target population strongly influenced the required usability and communication strategy of the system. Survey results showed that a large proportion of users had limited educational attainment—for instance, 44% completed only primary school and 7% had no formal education. This finding placed a strict limit on the technical complexity that the system could impose on the user, a necessary consideration for any system deployed in areas with low literacy rates.

Due to this low literacy level, the system was required to adopt an extremely simple, visual, and non-text-intensive interface for data input and consumption tracking. While limited educational attainment constrains access to secure, formal jobs, the data also indicated that education was widely recognized as a critical path to reducing inequality. The system leveraged this finding by designing its educational module to explicitly link sustainable behavior to economic returns (e.g., {X amount saved} on utilities), transforming abstract environmental awareness into a tangible financial incentive prioritized by the vulnerable user base.

• Gender Roles and Control Over Low-Carbon Consumption Investment

Gender patterns were identified as a key structural factor influencing resource control and the adoption of major sustainable changes in the household. The findings showed that while women were often responsible for managing daily consumption (food and fuel procurement), male-headed households dominated financial decision-making and generally benefited from greater economic opportunities.

This disparity meant that to secure investment in larger low-carbon upgrades (e.g., a more efficient stove), the system needed a targeted advocacy strategy. The data mandated the design of a feature capable of generating simple, financially-focused justification reports that could be used by female members to gain approval from the male financial decision-maker. Furthermore, the structural barriers faced by women, such as cultural beliefs 26% and caregiving responsibilities 14% that restrict stable income, highlighted the need for the system's aggregated data to inform local policy aimed at expanding women's economic empowerment in green sectors. Increasing women's control over household income would, in turn, increase the household's overall capacity to drive and adopt effective low-carbon solutions.

5. Conclusion and Recommendations

5.1 Conclusion

This study has illuminated the socioeconomic context of the target users, establishing the multifaceted dynamics of household demographics and income inequalities that directly impact the design and adoption of the Web-Based Carbon Footprint System. The findings underscore that large household sizes, limited educational attainment, and gender disparities are significant constraints that restrict the household's financial capacity to adopt low-carbon solutions.

The predominance of large households, with 72% comprising five to six members, requires the system to scale its CO₂ calculation based on high consumption baselines, while the low-income bracket (57% earning low monthly wages) necessitates that all system recommendations focus on cost-saving behavioral changes rather than high-capital investments.

Education emerges as a critical factor influencing system usability, as the high proportion of users with only primary schooling demands an extreme interface simplicity using visual cues. Finally, gender dynamics are key to implementation, as male control over major financial decisions requires the system to generate financial justification reports to secure investment in efficiency upgrades, while addressing structural barriers for women is necessary to enhance overall household economic resilience for climate action. In essence, the success of the localized carbon footprint system hinges entirely on its ability to mitigate these socioeconomic barriers by prioritizing economic benefit and accessibility.

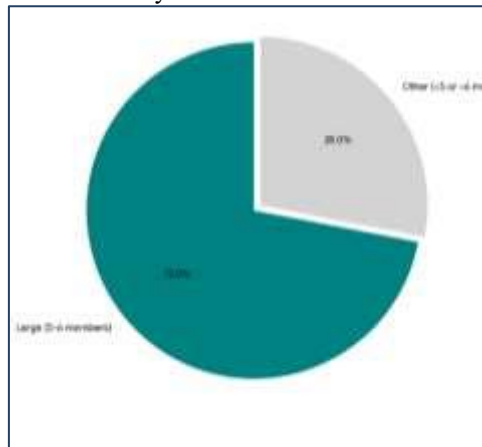


Figure 7: The Strains on carbon intensive category
Source: Author 2025

5.2 Recommendations

The following recommendations are designed for policymakers and community leaders to enhance the structural environment, making the Web-Based Carbon Footprint System more effective, widely adopted, and impactful in achieving urban emission reduction goals:

- Enhancing Access and Financial Capacity for Efficiency Interventions
- Policymakers should implement targeted subsidy programs or microfinance schemes specifically for high-efficiency cooking and energy technologies (e.g.) improved charcoal stoves, efficient LPG. These initiatives should focus on large households with high dependency ratios, as they experience the greatest financial strain and offer the highest potential for emission reduction per unit of subsidy.
- Vocational training and adult literacy programs should be integrated with environmental education, teaching practical skills that directly relate to household energy management and cost saving, thereby bolstering user understanding of the system's recommendations.
- Strengthening Foundational Data and Social Protection
- Social protection measures, such as targeted cash transfers or food vouchers, should be structured to include incentives or requirements for participating in sustainable practices (e.g., registering for the carbon footprint system or showing proof of food waste reduction). This can alleviate immediate financial pressures while promoting resilience against poverty and encouraging climate-positive behavior.
- Investment in high-quality, continuous localized emission factor data collection is critical to ensure the system's long-term accuracy and relevance to the evolving urban energy and transport mix.

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