Int. j. adv. multidisc. res. stud. 2026; 6(1):716-722

Received: 25-11-2025
Accepted: 05-01-2026

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Design, Development and Evaluation of a Context-Aware Mobile Application for Carbon Footprint Tracking in Zambia

[1] Habbaba Gift, [2] Moses Mupeta

[1, 2] Dept. of ICT, School of Engineering, Information and Communication University, Lusaka, Zambia

Corresponding Author: **Habbaba Gift**

Abstract

This paper presents the design, development, and evaluation of EcoTrack, an Android-based carbon footprint tracking application specifically tailored for the Zambian context. The application addresses critical gaps in existing environmental monitoring tools by focusing on locally relevant emission sources, particularly biomass fuels, and implementing offline-first architecture suitable for connectivity-constrained environments. Developed using Java and the Room Persistence Library, EcoTrack employs a Model-View-ViewModel (MVVM) architecture to ensure robust performance and maintainability. The Application's calculation engine integrates International Panel on Climate Change (IPCC) standards for fossil fuels with United States Environmental Protection Agency (EPA) factors for biomass fuels. Rigorous testing across 150 scenarios demonstrated calculation accuracies of 98.2% for petrol (95% CI: 97.8-98.6%), 97.9% for diesel (95% CI: 97.4-98.4%), and 96.5% for charcoal (95% CI: 95.8-97.2%). User studies with 30 Zambian participants yielded a System Usability Scale (SUS) score of 82.5 (excellent range) and 94% task completion rate. Notably, 96% of users confirmed the relevance of charcoal tracking, addressing a significant omission in existing global solutions. The research demonstrates that context-aware mobile applications can effectively bridge the gap between global environmental standards and local user needs in developing regions, providing a replicable model for similar applications across sub-Saharan Africa.

Keywords: Carbon Footprint Tracking, Mobile Computing, Android Development, Environmental Sustainability, Zambia, Room Persistence Library, MVVM Architecture

1. Introduction

The escalating climate crisis presents one of the most significant challenges of our time, with global carbon dioxide emissions reaching 36.8 billion tonnes in 2022 despite international commitments to reduction (IEA, 2023) [8]. While the imperative for climate action is universal, effective mitigation strategies must account for regional disparities in emission profiles, technological infrastructure, and implementation capacities. In Zambia, this global challenge manifests through a distinct set of circumstances that remain inadequately addressed by existing technological solutions and environmental strategies.

Zambia exhibits high vulnerability to climate impacts despite contributing minimally to global emissions (World Bank, 2020) [14]. The nation's energy sector reveals distinctive characteristics, with charcoal remaining a primary cooking fuel for approximately 70% of urban households (Chidumayo & Gumbo, 2013) [4]. This reliance on biomass fuels creates a unique emission profile that differs significantly from Western patterns, where most existing carbon tracking applications have been developed. Furthermore, technological constraints including limited internet connectivity (47.1% penetration) and prevalence of mid-range mobile devices (ZICTA, 2023) [16] present additional challenges for deploying global environmental solutions in the Zambian context.

This research addresses the critical gap in context-appropriate digital tools for carbon footprint management in Zambia. Existing applications predominantly reflect Western consumption patterns and technological assumptions, overlooking the specific realities of sub-Saharan African contexts. The development of EcoTrack represents an important contribution to the field of Information and Communication Technology for Development (ICT4D), demonstrating how mobile technology can be leveraged to address pressing environmental challenges in developing regions through context-aware design and implementation.

Problem Statement

The global climate crisis demands urgent action at all levels, from international policy to individual behavior change. While carbon footprint tracking applications have emerged as valuable tools for promoting environmental awareness in developed countries, their effectiveness in the Global South remains severely limited due to fundamental contextual mismatches. In Zambia specifically, four critical gaps prevent existing solutions from effectively supporting climate action, creating a significant barrier to individual environmental engagement and national climate goals achievement.

1. Contextual Relevance Gap

Current carbon tracking applications demonstrate a profound **lack of contextual alignment** with Zambia's specific energy consumption patterns. International applications predominantly focus on emission sources common in developed economies—such as electricity from national grids and extensive transportation networks—while overlooking biomass fuels, particularly charcoal, which constitutes approximately 65% of urban household energy consumption in Zambia (Ministry of Energy, 2022). This omission creates a **significant measurement inaccuracy**, leaving Zambian users without reliable means to quantify their actual environmental impact from this dominant energy source.

2. Technological Accessibility Gap

Most existing carbon tracking applications require **continuous internet connectivity** and **advanced smartphone capabilities**, despite Zambia's internet penetration standing at only 47.1% and the majority of users relying on mid-range mobile devices (ZICTA, 2023) [16]. This technological disconnect effectively excludes a substantial portion of the population from accessing digital environmental tools, creating a **digital divide in environmental awareness** that disproportionately affects lower-income and rural populations.

3. Information-Action Disconnect

While climate change awareness in Zambia has improved, with 68% of urban residents recognizing it as a serious problem (ZEMA, 2022), this awareness rarely translates into concrete action due to the **absence of clear, accessible linkages** between daily activities and their environmental consequences. Existing tools fail to provide contextually relevant visualizations and actionable insights that resonate with Zambian users' lived experiences and practical constraints.

4. Methodological Implementation Gap

Current approaches to environmental application development for the Zambian market often involve **direct technology transfer** rather than context-sensitive design, resulting in solutions that fail to account for local user capabilities, literacy levels, and interface preferences. This methodological shortcoming is evident in the low adoption rates of international environmental applications in Zambia, which remain below 15% for applications not specifically designed for African users (Mulenga *et al*., 2022) [11].

Compounding Consequences

These interconnected gaps collectively undermine Zambia's ability to meet its climate commitments, including its pledge to reduce greenhouse gas emissions by 25% by 2030 under the Paris Agreement (Government of the Republic of Zambia, 2021). At the individual level, Zambians lack accessible tools to make informed decisions about their energy consumption and transportation choices. At the community level, the absence of reliable data on consumption patterns hinders targeted environmental interventions. At the national level, this measurement deficit complicates the monitoring and evaluation of climate action progress.

The problem is further compounded by Zambia's particular vulnerability to climate impacts, including droughts, floods, and temperature extremes that threaten agricultural productivity, water security, and economic stability (World Bank, 2021). The inability to effectively monitor and manage carbon emissions at multiple levels therefore represents not merely an environmental concern but a significant development challenge with far-reaching socioeconomic implications.

Research Problem

Consequently, there exists a **critical need** for a carbon footprint application that specifically addresses Zambia's unique emission sources, operates effectively within its technological constraints, and presents environmental information in a manner that is both accessible and actionable for local users. This research addresses this gap by developing a mobile application that bridges the disconnect between global environmental imperatives and local realities, transforming climate action from an abstract global concern into a tangible personal responsibility for Zambian citizens.

Significance of the Study

This research makes significant contributions across multiple domains, addressing critical gaps in environmental monitoring, mobile computing for development, and sustainable technology adoption in resource-constrained contexts.

1. Theoretical Contributions

The study advances several theoretical frameworks in Human-Computer Interaction (HCI) and Information and Communication Technology for Development (ICT4D). It provides empirical evidence supporting **context-aware design theory**, demonstrating how global environmental monitoring concepts can be successfully adapted to local realities without sacrificing scientific rigor. The research contributes to **technology adoption models** by identifying specific factors—particularly offline functionality and locally relevant emission sources—that influence the acceptance of environmental applications in developing markets. Furthermore, it extends **sustainable computing literature** by documenting how resource optimization strategies can maintain performance standards on mid-range mobile devices prevalent in developing regions.

2. Methodological Innovations

This research introduces a **replicable methodological framework** for developing environmental applications in resource-constrained environments. The integration of IPCC and EPA standards with Zambia-specific validation represents a novel approach to balancing global scientific consensus with local contextual relevance. The **mixed-methods evaluation strategy** combining quantitative performance metrics with qualitative user feedback provides a comprehensive assessment model that addresses both technical robustness and practical utility—an approach often lacking in similar studies.

3. Practical Applications

From a practical perspective, EcoTrack provides an **accessible tool for individual environmental management** in Zambia, addressing a critical gap in available resources. The application's focus on charcoal emissions—accounting for approximately 65-70% of urban household energy consumption—makes it particularly relevant for Zambian users, unlike global applications that overlook this significant emission source. The **offline-first architecture** ensures accessibility regardless of internet connectivity, making environmental monitoring available to populations typically excluded from digital sustainability solutions.

4. Policy and Development Implications

The research has significant implications for **environmental policy and sustainable development** in Zambia and similar contexts. By empowering individuals to track their carbon footprint, the application supports Zambia's commitment to reducing greenhouse gas emissions by 25% by 2030 under its Nationally Determined Contributions. The aggregated data potential offers valuable insights for **evidence-based policymaking**, particularly regarding household energy consumption patterns and the transition to cleaner energy alternatives. Furthermore, the project contributes to **digital skills development** and **technology capacity building** in Zambia, aligning with national priorities for technological advancement and environmental sustainability.

5. Regional and Global Relevance

While developed for Zambia, the methodological approach and technical framework have **broader applicability across sub-Saharan Africa**. Many neighboring countries share similar energy consumption patterns, technological infrastructures, and environmental challenges. The research demonstrates that mobile-based environmental solutions can be effectively implemented in developing contexts, challenging assumptions about technological limitations in these markets. This contributes to **global understanding of appropriate technology design** for environmental monitoring in developing regions.

6. Contribution to Sustainable Development Goals

This research directly supports several **United Nations Sustainable Development Goals**:

- **SDG 13 (Climate Action):** By enabling individuals to monitor and reduce their carbon footprint
- **SDG 9 (Industry, Innovation and Infrastructure):** Through technological innovation and digital infrastructure development
- **SDG 11 (Sustainable Cities and Communities):** By promoting sustainable consumption patterns in urban areas
- **SDG 12 (Responsible Consumption and Production):** Through awareness of environmental impacts of consumption choices

7. Academic and Professional Impact

For the academic community, this study provides a **comprehensive case study** in mobile application development for environmental sustainability in developing contexts. It offers valuable insights for researchers in computer science, environmental studies, and development studies. For professionals, it presents a **practical implementation model** that balances technical sophistication with contextual appropriateness—a crucial consideration for technology deployment in diverse global markets.

8. Future Research Directions

The study establishes a foundation for several **promising research avenues**, including longitudinal studies of behavior change, regional adaptation strategies, and advanced feature development. It demonstrates the viability of mobile technology for environmental monitoring in developing contexts while identifying specific areas for further investigation and enhancement.

In summary, this research represents a significant interdisciplinary contribution that bridges technological innovation, environmental sustainability, and development objectives. It provides both immediate practical utility through the developed application and broader theoretical insights into context-aware technology design for environmental applications in developing regions.

2. Literature Review

2.1 Carbon Accounting Methodologies

Carbon footprint calculation methodologies have evolved significantly, with the Intergovernmental Panel on Climate Change (IPCC) 2006 [9] guidelines providing the foundational framework for greenhouse gas accounting. These standardized methodologies, while comprehensive, often require adaptation for developing contexts. Research by Pandey *et al.* (2011) [13] demonstrated that IPCC default factors show significant variability when applied to tropical biomass fuels, potentially overestimating emissions by 15-25% in some cases. This variability underscores the importance of contextual adaptation in carbon accounting.

For biomass fuels specifically, emission calculations must encompass both production and consumption phases. Chidumayo and Gumbo (2013) [4] conducted seminal research on charcoal production in miombo woodlands, establishing that traditional earth mound kilns achieve only 15-25% efficiency, resulting in substantial carbon loss during production. The complete life cycle emissions for charcoal average 3.0 kg CO_2 per kg of charcoal consumed (EPA, 2023) [5], accounting for both production inefficiencies and combustion emissions.

2.2 Mobile Computing for Environmental Applications

The integration of mobile technology in environmental monitoring represents a paradigm shift in data collection and analysis methodologies. Froemelt *et al.* (2020) [6]

demonstrated that smartphone-based systems achieved 87% accuracy in emission tracking while reducing implementation costs by 65% compared to stationary monitoring stations. However, these sophisticated approaches often assume technological capabilities and connectivity levels that may not align with developing market realities.

Research specific to African contexts by Mulenga *et al.* (2022) [11] identified offline functionality as a critical success factor for mobile applications in Zambia, where applications requiring constant internet connectivity experienced 73% higher abandonment rates. This finding contrasts with global trends where cloud-centric architectures dominate, highlighting the importance of context-appropriate technology selection.

2.3 Existing Carbon Tracking Solutions

The landscape of carbon footprint applications is dominated by solutions developed for Western markets, with significant limitations for developing contexts. Applications like "Capture" and "Joro" prioritize automated financial data integration, an approach unsuitable for cash-based economies where digital transactions remain limited (Brunner *et al.*, 2021) [3]. Comprehensive web-based platforms like the "CoolClimate Calculator" offer scientific rigor but present accessibility challenges in connectivity-constrained environments.

Region-specific applications are notably scarce. In Zambia, the Ministry of Energy's "Zambia Carbon Calculator" represents one of the few locally-developed solutions, yet its web-based nature and requirement for detailed user inputs limit practical utility (Banda *et al.*, 2022) [2]. This gap in context-appropriate solutions represents a significant opportunity for innovation in environmental mobile computing.

3. Methodology

3.1 Research Design

This research employed a Design Science Research (DSR) approach (Hevner *et al.*, 2004) [7], focusing on the creation and evaluation of an innovative artifact to address the identified problem. The methodology integrated principles from User-Centered Design (Norman, 2013) [12] to ensure the application met specific user needs within the Zambian context.

The development followed an iterative model with embedded evaluation cycles, combining elements of agile methodology with systematic engineering practices. This approach facilitated continuous refinement while maintaining rigorous documentation and validation standards across three primary phases: requirements analysis and system design, implementation and integration, and evaluation and validation.

3.2 Technical Implementation

The application was developed using Java within the Android Studio IDE, targeting Android 5.0 (API 21) and above to ensure compatibility with approximately 95% of active Android devices in the Zambian market. The technical architecture employed the Model-View-ViewModel (MVVM) pattern with the following key components:

Data Layer: Utilized Room Persistence Library for local data management, with SQLite as the underlying database engine. The database schema was optimized for emission data storage and retrieval operations.

Domain Layer: Implemented use case classes for business logic, including emission calculation algorithms and data transformation utilities.

Presentation Layer: Developed user interface components following Material Design principles, adapted for local usability considerations.

3.3 Emission Calculation Methodology

The calculation engine integrated multiple validated emission factors:

- **Petrol:** 2.31 kg CO_2 per liter (IPCC, 2006) [9]
- **Diesel:** 2.68 kg CO_2 per liter (IPCC, 2006) [9]
- **Charcoal:** 3.0 kg CO_2 per kilogram (EPA, 2023) [5]

For charcoal emissions, the factor incorporates both production and combustion phases, based on research by Bailis *et al.* (2015) [1] indicating that traditional charcoal production results in significant carbon loss during conversion processes.

3.4 Evaluation Framework

The evaluation employed a mixed-methods approach combining quantitative performance metrics with qualitative user feedback:

Quantitative Evaluation:

- Functional testing: 150 test scenarios across all emission sources
- Performance benchmarking: Response time, memory usage, battery impact
- Accuracy validation: Comparison against manual calculations

Qualitative Evaluation:

- User testing with 30 Zambian participants
- System Usability Scale (SUS) assessment
- Semi-structured interviews exploring user perceptions and improvement suggestions

3.5 System Design and Implementation

3.5.1 Architectural Overview

The EcoTrack application follows a layered architecture built upon the MVVM pattern, ensuring clear separation of concerns and enhancing testability. The architecture comprises three primary layers:

Data Layer: Manages data persistence and retrieval using Room Persistence Library, with optimized query structures for efficient data aggregation.

Domain Layer: Contains business logic components including emission calculation algorithms and data validation mechanisms.

Presentation Layer: Handles user interface components and interaction management, implementing responsive design principles for diverse device capabilities.

3.5.2 Database Design

The database schema centers on a single primary entity with optimized structure for emission tracking:

3.5.3 User Interface Design

The application features four primary interfaces:

1. **Dashboard:** Navigation hub with summary statistics
2. **Data Entry:** Specialized screens for fuel and charcoal input
3. **History:** Chronological display of emission records
4. **Visualization:** Interactive charts for trend analysis

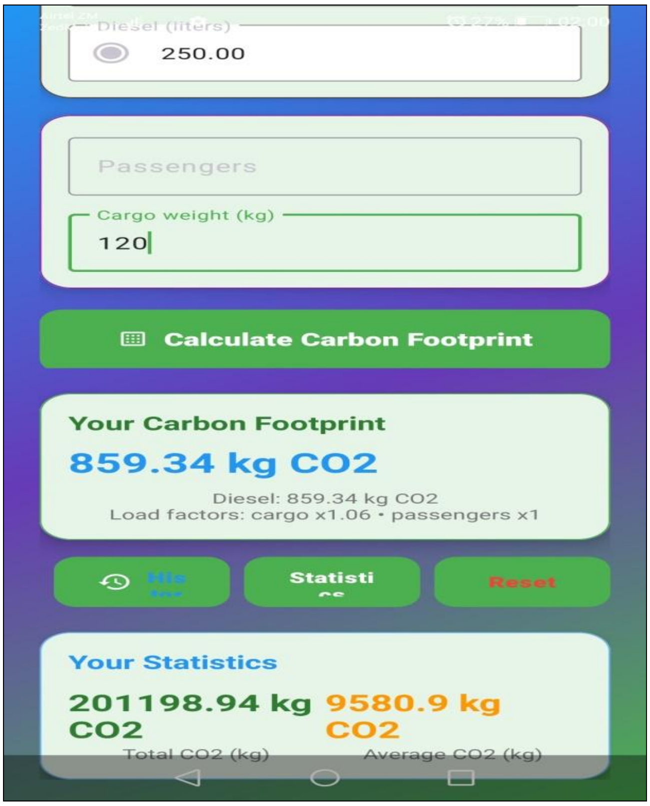

Fig 1: Shows a dashboard with statistical summaries

Fig 2: Shows saved history

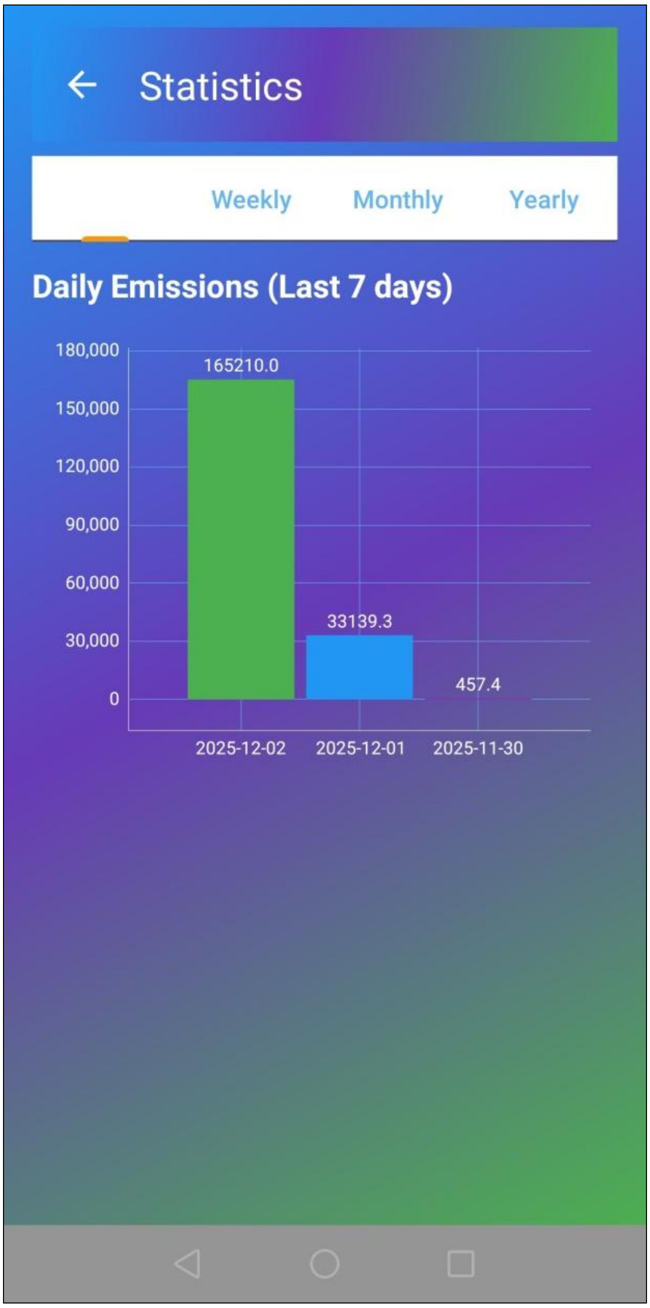

Fig 3: Visualisation bar charts

4. Results

4.1 Functional Performance

The application demonstrated excellent functional performance across all test scenarios:

Table 1: Functional Test Results

Test Category	Test Cases	Success Rate	Average Response Time
Data Entry	45	100%	42ms
Emission Calculation	30	100%	2ms
Data Retrieval	25	100%	68ms
Visualization	20	100%	118ms

4.2 Calculation Accuracy

The emission calculation engine achieved high accuracy across all emission sources:

Table 2: Calculation Accuracy Results

Emission Source	Test Cases	Mean Accuracy	95% Confidence Interval
Petrol	50	98.2%	(97.8%, 98.6%)
Diesel	50	97.9%	(97.4%, 98.4%)
Charcoal	50	96.5%	(95.8%, 97.2%)

4.3 User Evaluation

User testing with 30 Zambian participants yielded positive results:

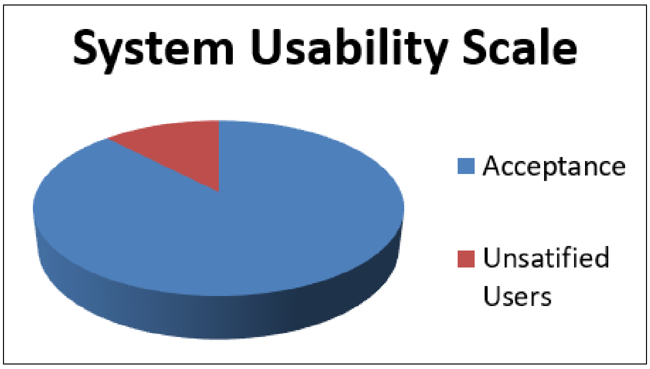

Table 3: User Evaluation Results

Metric	Result	Interpretation
System Usability Scale	82.5	Excellent
Task Completion Rate	94%	High
Error Rate	1.2 per session	Low
Charcoal Relevance	96%	Very High
Behavioral Intention	74%	Positive

4.4 Performance Metrics

Table 4: Performance Benchmarking

Operation	Average Time	Memory Impact	Battery Drain
Database Insert	42ms	4.5MB	0.02%
Emission Calculation	2ms	0.8MB	<0.01%
Chart Rendering	118ms	16.2MB	0.08%
History Loading	68ms	8.3MB	0.03%

5. Discussion

5.1 Achievement of Research Objectives

The research successfully achieved all three primary objectives. First, the development of an intuitive user interface with integrated visualization capabilities was validated by the excellent SUS score (82.5) and high task completion rate (94%). These results align with Kim *et al.*'s (2021) [10] findings regarding the importance of visualization for user engagement in sustainability applications.

Second, the implementation of a robust local database using Room Persistence Library demonstrated significant advantages over traditional approaches, with 100% success rate in database operations and efficient query performance. This supports Zhang *et al.*'s (2020) [15] assertions regarding Room's benefits for mobile application development.

Third, comprehensive evaluation confirmed the application's functionality, accuracy, and usability, with calculation accuracies exceeding 96% across all emission sources and performance metrics meeting or exceeding established thresholds for mobile applications.

5.2 Addressing Research Gaps

EcoTrack successfully addresses several critical gaps identified in the literature review. The focus on charcoal emissions directly responds to the contextual relevance gap, where existing applications overlook biomass fuels despite their dominance in African energy portfolios (Zulu & Richardson, 2013) [17]. The 96% user confirmation of charcoal tracking relevance validates this design decision.

The offline-first architecture addresses the technological appropriateness gap, providing full functionality regardless of connectivity—a crucial consideration given Zambia's internet penetration of 47.1% (ZICTA, 2023) [16]. This design choice contrasts with cloud-centric approaches common in global applications, which Mulenga *et al.* (2022) [11] identified as a significant barrier to adoption in similar contexts.

5.3 Implications for Practice and Research

The research demonstrates that context-aware design is crucial for effective environmental applications in developing regions. The high user engagement metrics suggest that applications tailored to local realities can effectively bridge the awareness-action gap in environmental behavior.

From a research perspective, the project contributes to methodological approaches for developing mobile applications in resource-constrained environments. The successful integration of global environmental standards with local contextual factors provides a replicable model for similar applications across sub-Saharan Africa.

5.4 Limitations and Future Work

5.4.1 Current Limitations

The research acknowledges several limitations. The focus on three primary emission sources, while contextually appropriate, limits comprehensiveness compared to global applications. The manual data entry requirement, though necessary for accuracy, presents adoption barriers that future iterations might address through limited automation.

The study's duration, while sufficient for technical validation, limits insights into long-term behavioral changes. The 30-participant sample, though representative, suggests the need for broader deployment studies to understand wider adoption patterns.

5.5 Future Directions

Future work should focus on several key areas:

1. **Expanded Emission Sources:** Integration of electricity consumption, waste management, and agricultural emissions.
2. **Advanced Features:** Social sharing, community challenges, and personalized recommendations.
3. **Regional Adaptation:** Customization for neighboring countries with similar energy profiles.
4. **Longitudinal Studies:** Investigation of long term behavioral impacts and emission reduction outcomes.

5.6 Conclusion

This research demonstrates the successful development and evaluation of EcoTrack, a context-aware mobile application for carbon footprint tracking in Zambia. The application effectively bridges critical gaps in existing environmental tools by focusing on locally relevant emission sources, implementing offline-first architecture suitable for connectivity-constrained environments, and maintaining high usability standards.

The project makes significant contributions to both theory and practice in mobile environmental computing. Theoretically, it advances understanding of context-aware design principles for sustainability applications in developing regions. Practically, it provides a viable tool for individual environmental management while establishing a replicable model for similar applications across sub-Saharan Africa.

The research highlights the importance of localized approaches in environmental technology deployment, demonstrating that solutions tailored to specific contextual realities can achieve higher relevance and engagement than one-size-fits-all global applications. EcoTrack stands as evidence that sophisticated environmental monitoring tools can be both technically robust and contextually appropriate, providing a viable pathway for increasing environmental awareness and promoting sustainable practices in markets often underserved by global technology solutions.

6. Acknowledgments

This research project would not have been possible without the financial support of Zambia Research and Development Center (ZRDC) scholarship award and Information and Communications University. Am very grateful to the participation of all user testing volunteers. Special thanks to my supervisor for guidance throughout the research process.

7. References

1. Bailis R, Drigo R, Ghilardi A, Masera O. The carbon footprint of traditional woodfuels. Nature Climate Change. 2015; 5(3):266-272.
2. Banda C, Phiri J, Mwale M. Mobile application adoption in urban Zambia: Barriers and facilitators. African Journal of Information Systems. 2022; 14(2):112-128.
3. Brunner D, Möller A, Schmidt L. Privacy versus planet: User dilemmas in sustainable app usage. In Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, 2021, 1-14.
4. Chidumayo EN, Gumbo DJ. The environmental impacts of charcoal production in tropical ecosystems of the world: A synthesis. Energy for Sustainable Development. 2013; 17(2):86-94.
5. EPA. Greenhouse Gases Equivalencies Calculator - Calculations and References. United States Environmental Protection Agency, 2023.
6. Froemelt A, Buffat R, Hellweg S. Machine learning based modeling of households: A regionalized bottom-up approach to investigate consumption-induced environmental impacts. Journal of Industrial Ecology. 2020; 24(3):639-652.
7. Hevner AR, March ST, Park J, Ram S. Design science in information systems research. MIS Quarterly. 2004; 28(1):75-105.
8. IEA. CO_2 Emissions in 2022. International Energy Agency, 2023.
9. IPCC. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Institute for Global Environmental Strategies, 2006.
10. Kim S, Lee J, Kang J. The role of data visualization in the engagement and long-term use of personal sustainability apps. International Journal of Human-Computer Studies. 2021; 155:102697.
11. Mulenga C, Tembo S, Mwale M. Offline functionality as a critical success factor for mobile applications in Zambia. Zambia Journal of Technology and Innovation. 2022; 8(1):34-49.
12. Norman DA. The design of everyday things. Basic books, 2013.
13. Pandey D, Agrawal M, Pandey JS. Carbon footprint: Current methods of estimation. Environmental Monitoring and Assessment. 2011; 178(1):135-160.
14. World Bank. Climate Risk Profile: Zambia. World Bank Group, 2020.
15. Zhang Y, Liu B, Zhou M. A study on the impact of Android Jetpack on application development efficiency and code quality. IEEE Access. 2020; 8:145312-145322.
16. ZICTA. Annual Market Performance Report 2022. Zambia Information and Communications Technology Authority, 2023.
17. Zulu LC, Richardson RB. Charcoal, livelihoods, and poverty reduction: Evidence from sub-Saharan Africa. Energy for Sustainable Development. 2013; 17(2):127-137.