# Assessment of Scope 1 Carbon Footprint in Higher Education: A Case Study of Addis Ababa Science and Technology University

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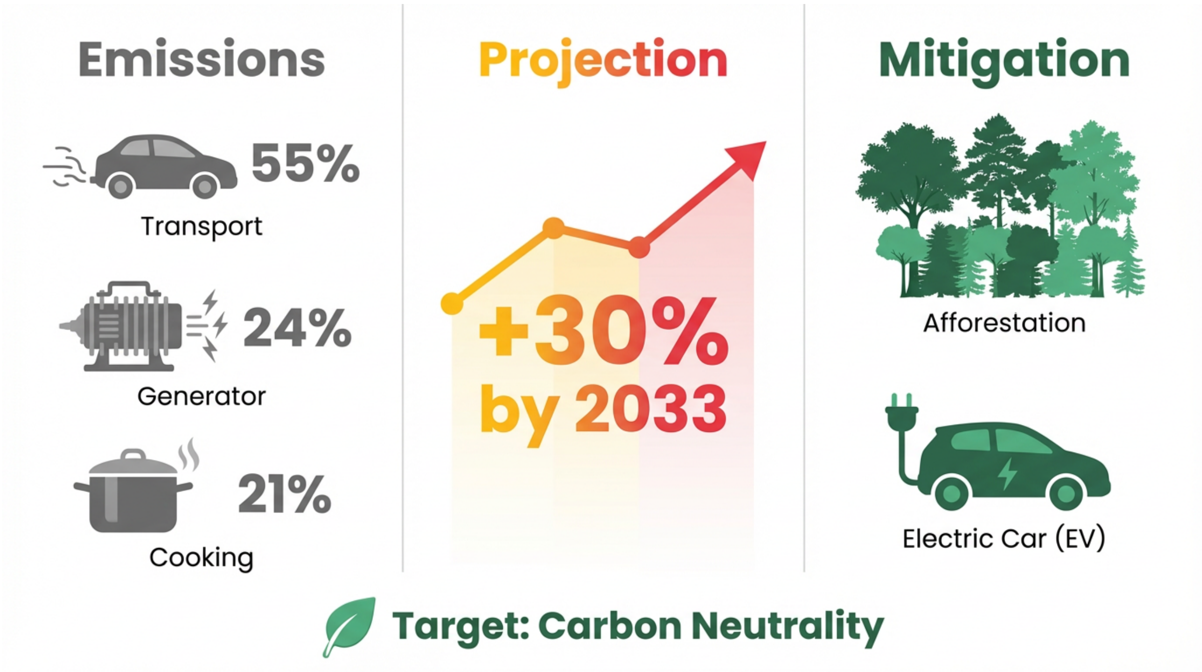
## Graphical Abstract



# Assessment of Scope 1 Carbon Footprint in Higher Education: A Case Study of Addis Ababa Science and Technology University

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**Abstract**

This research estimates the Scope 1 carbon footprint (CFP) of Addis Ababa Science and Technology University (AASTU), a higher education institution with 8,000 students, using the Greenhouse Gas (GHG) Protocol. The study focuses exclusively on direct emissions from sources owned or controlled by the university, excluding Scope 2 (purchased electricity from Ethiopia's predominantly renewable grid) and Scope 3 (indirect emissions) due to data constraints. The total annual Scope 1 CFP was calculated as 1,136 tons of $CO_2$e, with transportation (55%), emergency generators (24.4%), and student cafeteria cooking (20.6%) as primary sources. Compared to similar institutions, AASTU's CFP is relatively low due to institutional characteristics and Ethiopia's renewable energy context. Future projections based on geometric progression indicate a potential increase to 1,464 tons of $CO_2$e within ten years. Two mitigation strategies were evaluated: afforestation with 58,562 eucalyptus trees over 23.42 hectares for carbon sequestration, and replacement of diesel vehicles with electric vehicles. A comprehensive cost-benefit analysis adjusted for Ethiopia's inflation rate was conducted, with afforestation costs estimated at 3,251,417.6 ETB (plug seedlings) or 670,807.8 ETB (field-grown seedlings), and vehicle electrification requiring a net investment of 3,430,000 ETB. The study establishes a Scope 1 emissions baseline and provides actionable recommendations for achieving carbon neutrality in higher education institutions.

**Keywords:** Scope 1 Carbon Footprint; GHG Protocol; Climate Change Mitigation; Carbon Sequestration; Higher Education; Sustainability; Ethiopia.

## 1.0 Introduction

Climate change represents one of the most significant global challenges of the 21st century, with far-reaching implications for ecological systems, human health, and economic stability [1]. The increasing concentration of greenhouse gases (GHGs) in the atmosphere, primarily driven by anthropogenic activities, has led to unprecedented changes in global climate patterns, including rising temperatures, extreme weather events, and sea-level rise. In response to this crisis, there is growing recognition of the need for comprehensive action across all sectors of society, including higher education institutions (HEIs) which serve as both centers of knowledge production and significant contributors to environmental impacts [8].

Higher Education Institutions play a dual role in climate change mitigation: as operational entities with substantial resource consumption and as educational institutions with the responsibility to model sustainable practices [17]. With campuses often functioning as small cities, HEIs consume significant amounts of energy, generate waste, and maintain

transportation systems that collectively contribute to greenhouse gas emissions. Quantifying these emissions through carbon footprint assessment represents a critical first step toward developing effective mitigation strategies and achieving sustainability goals [15].
The concept of carbon footprint, derived from the broader ecological footprint framework developed by [19], provides a specific metric for assessing an organization's contribution to climate change through GHG emissions. For universities, conducting carbon footprint assessments enables the identification of major emission sources, establishes baseline data for tracking progress, and informs strategic planning for emissions reduction [2]. These assessments typically follow the GHG Protocol framework, which categorizes emissions into three scopes: Scope 1 (direct emissions), Scope 2 (indirect emissions from purchased energy), and Scope 3 (other indirect emissions) [20].

### 1.1 Literature Review

Research on university carbon footprints has gained significant momentum globally over the past two decades. Studies from various regions have employed different methodologies and scopes. In North America, comprehensive assessments often include all three scopes [7, 4], while in Europe, the focus varies by country and institutional capacity [18]. In developing regions, studies frequently focus on Scope 1 emissions due to data constraints and methodological challenges [10].
In Africa, limited research exists on institutional carbon footprints, with notable exceptions from South Africa [16], Kenya [10], and Nigeria [11]. These studies consistently identify transportation, energy consumption, and waste management as major emission sources. However, methodological approaches vary significantly, with some studies employing full life cycle assessments while others focus on specific emission sources.
This study addresses several gaps in the existing literature. First, it provides the first comprehensive assessment of a major Ethiopian university's carbon footprint. Second, it contextualizes the findings within Ethiopia's unique energy landscape, where the national grid is predominantly renewable. Third, it offers practical, locally-relevant mitigation strategies with detailed cost-benefit analyses.
This study focuses on Addis Ababa Science and Technology University (AASTU), a rapidly growing public university in Ethiopia established in 2011. With a current enrollment of approximately 8,000 students and ambitious expansion plans, AASTU represents an important case study for examining carbon management in the context of Ethiopian higher education. This research provides a foundational assessment of AASTU's Scope 1 emissions, establishing a baseline for future sustainability initiatives and contributing to the growing body of literature on carbon management in African higher education institutions.

## 2.0 Materials and Methods

### 2.1 Study Area and Scope

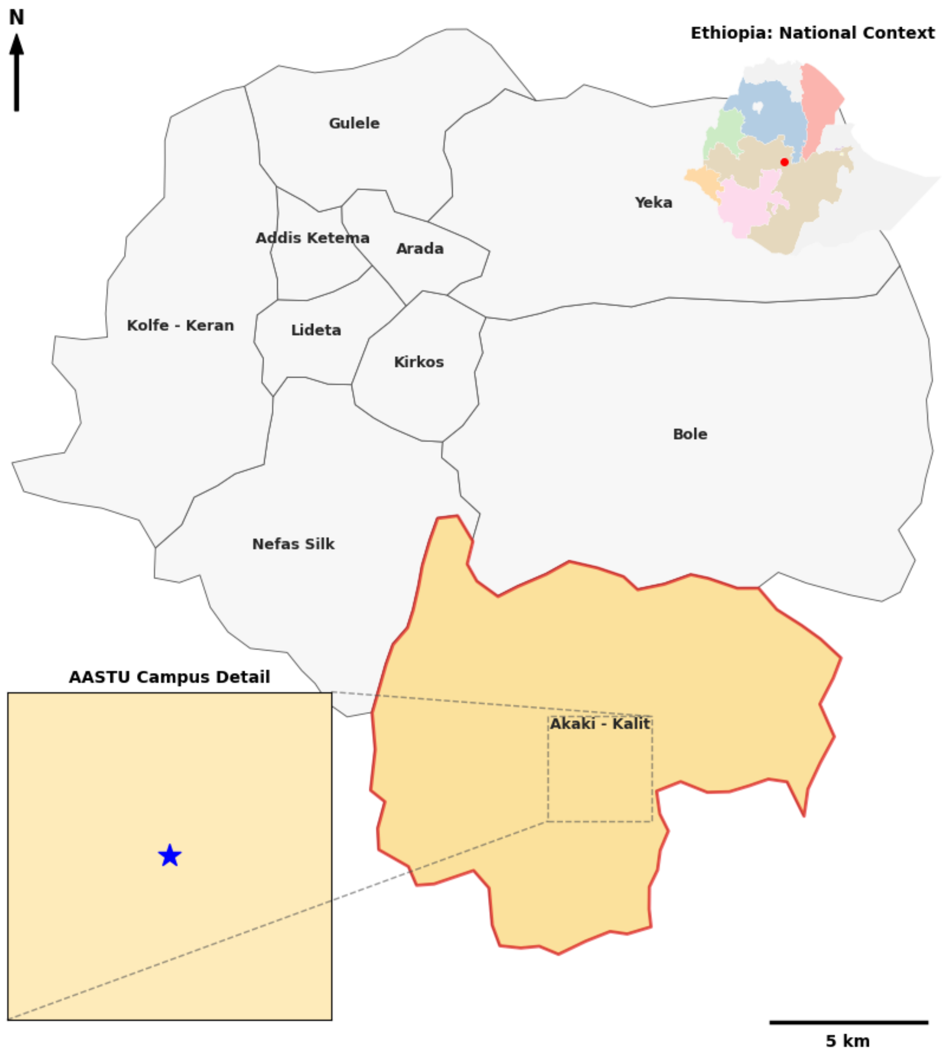


Figure 1: Map of Addis Ababa showing the study area in Akaki-Kaliti sub-city and the AASTU campus detail (Coordinates: 8.8852°N, 38.8098°E).

The study was conducted at the main campus of Addis Ababa Science and Technology University (AASTU), located at coordinates 8.8852°N, 38.8098°E in the Akaki Kality suburb of Addis Ababa, Ethiopia. Established in 2011, AASTU has rapidly grown to become one of Ethiopia's leading institutions for science and technology education, with a current student population of approximately 8,000 and plans for further expansion.
The assessment scope focused exclusively on Scope 1 emissions as defined by the GHG Protocol [20]. This scope selection was based on three methodological considerations: (1) **Scope 2 Exclusion Justification:** Ethiopia's national electricity grid is predominantly renewable, with hydropower accounting for approximately 92% of generation, wind power for 7%, and geothermal for less than 1% [13]. Following the GHG Protocol methodology, Scope 2 emissions from purchased electricity were excluded because Ethiopia's grid emission factor approaches zero. (2) **Scope 3 Exclusion Justification:** Scope 3 emissions were excluded due to significant data collection challenges, time constraints, and

budget limitations. (3) **Methodological Focus:** This study prioritizes establishing a robust baseline for Scope 1 emissions, aligning with recommendations for initial carbon footprint assessments in resource-constrained settings [12].
The operational boundaries included three major emission sources: university-owned transportation fleet, emergency electric generators, and cooking activities in student cafeterias. The temporal scope covered the 2022–2023 academic year.

### 2.2 Data Collection Methods

Primary data collection employed multiple approaches: (1) Institutional records review for fuel purchase records, maintenance logs, and vehicle usage reports; (2) Direct measurement of biomass consumption in student cafeterias; (3) Surveys and interviews with facility managers, transportation coordinators, and cafeteria staff; (4) Document analysis of institutional policies and sustainability reports. Secondary data included emission factors from IPCC EFDB and Ethiopia-specific environmental statistics.

### 2.3 Analytical Framework

The study employed the Greenhouse Gas Protocol as the primary analytical framework [20]. The fundamental calculation equation was:

$$E = AD \times EF \tag{1}$$

where $E$ represents total emissions, $AD$ is activity data, and $EF$ is the emission factor.

#### 2.3.1 Transportation Sector Calculations

$$E_{\text{transport}} = FC \times EF_{\text{fuel}} \times GWP \tag{2}$$

where $FC$ is fuel consumption in liters, $EF_{\text{fuel}}$ is the fuel-specific emission factor from IPCC (2019), and $GWP$ is the Global Warming Potential.

$$E_{\text{transport}} = DT \times FE \times EF_{\text{fuel}} \tag{3}$$

where $DT$ is distance traveled (km) and $FE$ is fuel efficiency (L/km).

#### 2.3.2 Emergency Generator Calculations

$$E_{\text{generator}} = FC_{\text{diesel}} \times EF_{\text{diesel}} \times \text{Operating Hours} \tag{4}$$

#### 2.3.3 Cooking Emissions Calculations

$$E_{\text{cooking}} = BM_{\text{consumed}} \times EF_{\text{biomass}} \tag{5}$$

### 2.4 Mitigation Strategy Analysis

#### 2.4.1 Afforestation for Carbon Sequestration

$$N_{\text{trees}} = \frac{E_{\text{total}}}{S_{\text{tree}}} \tag{6}$$

$$A_{\text{land}} = \frac{N_{\text{trees}}}{D_{\text{planting}}} \tag{7}$$

### 2.4.2 Vehicle Electrification

Net cost analysis following standard financial methods [5]:

$$\text{Net Cost} = C_{\text{purchase}} - R_{\text{sale}} + \sum_{t=1}^{n} \frac{(O_{\text{diesel}} - O_{\text{electric}})}{(1+r)^t} \tag{8}$$

## 2.5 Data Analysis and Projection

$$E_t = E_0 \times (1+r)^t \tag{9}$$

Growth rate assumptions were based on historical trends at AASTU. All financial analyses were adjusted for inflation using Ethiopia's historical rates.

## 3.0 Results

## 3.1 Current Carbon Footprint Composition

The comprehensive assessment revealed that AASTU's total annual Scope 1 carbon footprint is 1,136 tons of $CO_2$e (Table 2). The transportation sector emerged as the largest contributor at 55%.

Table 1: Emission factors used in carbon footprint calculation

| **Fuel/Source** | **Emission Factor** | **Unit** | **GWP** | **Source** |
|---|---|---|---|---|
| Diesel (Transport) | 2.68 | kg $CO_2$e/L | – | IPCC (2019) |
| Diesel (Stationary) | 2.68 | kg $CO_2$e/L | – | IPCC (2019) |
| Biomass (Wood) | 1747.2 | kg $CO_2$e/ton | – | IPCC (2019) |
| $CH_4$ | – | – | 28 | IPCC (2014) |
| $N_2O$ | – | – | 265 | IPCC (2014) |

Table 2: AASTU's annual Scope 1 carbon footprint by emission source

| **Emission Source** | **Emissions (t$CO_2$e)** | **Percentage** | **GHGP Scope** |
|---|---:|---:|---|
| University Vehicle Fleet | 624.8 | 55.0% | Scope 1 |
| Emergency Generators | 277.2 | 24.4% | Scope 1 |
| Student Cafeteria Cooking | 234.0 | 20.6% | Scope 1 |
| Total Scope 1 Emissions | 1,136.0 | 100.0% | |

## 3.2 Comparative Analysis

AASTU demonstrates relatively low emissions per capita (0.12 t$CO_2$e/person) compared to international benchmarks (Table 3).

## 3.3 Future Emission Projections

Based on geometric progression models (2% growth for transport and energy, 5% for cooking), emissions were projected to increase 30.3% over ten years, reaching approximately 1,481 tons $CO_2$e by 2033 (Table 4).

Table 3: Comparative Scope 1 carbon footprint analysis

| University | Country | Scope 1 ($tCO_2e$) | CFP/Capita |
|---|---|---|---|
| AASTU | Ethiopia | 1,136 | 0.12 |
| University of Haripur | Pakistan | 578.9 | 0.14 |
| University of Nairobi | Kenya | 15,240 | 0.38 |
| University of Cape Town | South Africa | 45,320 | 0.57 |
| Clemson University | USA | 27 | 0.01 |
| University of Cambridge | UK | 17,388 | 1.74 |

Table 4: 10-year Scope 1 carbon footprint projection

| Year | Transport ($tCO_2e$) | Energy ($tCO_2e$) | Cooking ($tCO_2e$) | Total ($tCO_2e$) |
|---|---|---|---|---|
| 2023 (Baseline) | 624.8 | 277.2 | 234.0 | 1,136.0 |
| 2024 | 637.3 | 282.7 | 245.7 | 1,165.7 |
| 2025 | 650.1 | 288.4 | 258.0 | 1,196.5 |
| 2026 | 663.1 | 294.1 | 270.9 | 1,228.1 |
| 2027 | 676.4 | 300.0 | 284.4 | 1,260.8 |
| 2028 | 689.9 | 306.0 | 298.6 | 1,294.5 |
| 2029 | 703.7 | 312.1 | 313.6 | 1,329.4 |
| 2030 | 717.8 | 318.4 | 329.2 | 1,365.4 |
| 2031 | 732.1 | 324.8 | 345.7 | 1,402.6 |
| 2032 | 746.8 | 331.3 | 363.0 | 1,441.1 |
| 2033 | 761.7 | 337.9 | 381.1 | 1,480.7 |

## 3.4 Mitigation Strategy Requirements

### 3.4.1 Afforestation

To sequester baseline emissions of 1,136 $tCO_2e$ requires 58,562 *Eucalyptus globulus* trees over 23.42 hectares (Table 5).

Table 5: Afforestation requirements for emission sequestration

| Time Period | Emissions ($tCO_2e$) | Trees Required | Land (ha) |
|---|---|---|---|
| Current Year | 1,136 | 45,450 | 18.18 |
| Next 5 Years | 1,283 | 51,307 | 20.52 |
| Next 10 Years | 1,464 | 58,562 | 23.42 |

### 3.4.2 Vehicle Electrification

Replacing six high-usage vehicles: net investment 3,430,000 ETB; payback period 2.3 years (Table 6).

## 3.5 Cost Analysis

Afforestation: plug seedlings 3,251,418 ETB total 10-year cost; field-grown seedlings 670,808 ETB (Table 7). Integrating both strategies would reduce emissions by approximately 55% immediately through vehicle electrification while establishing long-term carbon neutrality through afforestation.

## 4.0 Discussion

The dominance of transportation emissions (55%) at AASTU aligns with patterns observed in many university carbon footprint studies in developing countries [10, 11], though

Table 6: Vehicle electrification cost-benefit analysis

| Parameter | Diesel Fleet | Electric Fleet | Net Difference |
|---|---|---|---|
| Number of Vehicles | 6 | 6 | – |
| Purchase Cost (ETB) | – | 29,000,000 | – |
| Sale Revenue (ETB) | 25,770,000 | – | – |
| Annual Fuel Cost (ETB) | 1,560,000 | 468,000 | −1,092,000 |
| Annual Maintenance (ETB) | 312,000 | 156,000 | −156,000 |
| Payback Period (years) | – | – | 2.3 |
| Net Investment Required (ETB) | – | – | 3,430,000 |

Table 7: Afforestation cost analysis (inflation-adjusted)

| Cost Component | Plug Seedlings (ETB) | Field-Grown (ETB) |
|---|---|---|
| Initial Planting (Year 1) | 1,431,675 | 295,425 |
| Annual Planting (Years 2–10) | 1,819,743 | 375,383 |
| Total 10-Year Cost | 3,251,418 | 670,808 |
| Annual Average Cost | 325,142 | 67,081 |

the magnitude differs based on institutional characteristics [18]. The relatively low per capita emissions at AASTU compared to international benchmarks reflect both challenges and opportunities for maintaining low-emission growth as the institution expands [4].
The methodological approach demonstrates the applicability of the GHG Protocol in African university contexts [12]. The exclusive focus on Scope 1 emissions represents a practical approach for initial assessments in resource-constrained settings [21]. The choice of *Eucalyptus globulus* for afforestation warrants careful consideration of ecological impacts [9, 3]; future iterations should consider mixed-species plantings for biodiversity [14, 6].
The vehicle electrification strategy presents a compelling opportunity given Ethiopia's growing interest in electric mobility. The 2.3-year payback period is comparable to similar analyses [5]. The significant cost difference between seedling types (3.2M vs. 0.67M ETB) highlights the importance of careful cultivation method selection.

## 5.0 Conclusions

This study provides the first comprehensive assessment of the Scope 1 carbon footprint of Addis Ababa Science and Technology University, establishing a baseline of 1,136 tons of $CO_2$e annually with transportation as the dominant emission source. The projected increase to 1,464 tons $CO_2$e over ten years underscores the urgency of implementing mitigation measures. The evaluated strategies—afforestation and vehicle electrification—offer practical, cost-effective pathways toward carbon neutrality. However, the exclusive focus on eucalyptus should be reconsidered in favor of more ecologically diverse approaches. Future research should expand to Scope 3 emissions and develop institution-specific emission factors. Implementation of the proposed mitigation measures would position AASTU as a leader in campus sustainability in Ethiopia.

## Declarations

**Author contribution statement.** Walelign Melese: Conceptualization, methodology development, data collection, formal analysis, writing—original draft preparation, project administration. Robel Abebe: Methodology development, data collection, validation, visualization, writing—review and editing. Both authors have read and agreed to the published version of the manuscript.

**Consent and Ethical Approval.** Not applicable. This study used institutional records, surveys, and direct measurements; no human subjects research requiring ethical approval was conducted.

**Competing Interests.** Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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**Supplementary Material.** Supplementary materials including detailed calculation worksheets, emission factor sources, comparative data tables, and sensitivity analysis results are available from the corresponding author upon reasonable request.

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