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# Developing Baseline Carbon Footprint for Campus Commuting to Support Low-Carbon Policy Planning

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## Abstract

Malaysia has committed in Paris Agreement, through Nationally Determined Contribution (NDC) submitted to the United Nations Framework Convention on Climate Change, to reduce the greenhouse gas (GHG) emissions intensity of by 45% by 2030 relative to 2005 levels. This pledge requires that public sector organizations, including higher education institutions and government agencies, create comprehensive carbon footprint baselines as a foundation for evidence-based emissions reduction and accountability. In measuring organizational carbon footprints are usually categorized into Scope 1 (direct emissions from owned sources), Scope 2 (indirect emissions from purchased electricity), and Scope 3 (other indirect emissions). Scope 1 and Scope 2 emissions are well measured within educational institutions. While scope 3 emissions remain insufficiently quantified because they represent the largest part of total institutional emissions in staff commute. This study focuses on Scope 3 emissions related with staff commuting, a critical component of carbon management. This paper develops a baseline carbon footprint of campus commuting and examines its relevance for low-carbon transport policy planning for the institution. Data was collected through a survey involving 249 staff at Politeknik Sultan Abdul Halim Mu'adzam Shah. Commuting-related emissions were estimated using a distance-based emission factor approach aligned with the Intergovernmental Panel on Climate Change (IPCC) Guidelines. The results indicate a strong reliance on private car commuting, with long-distance commuters contributing to total emissions. By identifying baseline carbon footprint quantifying, this research shows how higher education institutions can form mitigation plans that enable evidence-based, low-carbon policy development in institutional governance.

*Keywords: - Carbon footprint, scope 3 emissions, higher education institutions*



## 1. Introduction

Under the Paris Agreement, Malaysia's Nationally Determined Contribution (NDC) aims to achieve a 45% reduction in GHG emissions intensity by 2030 relative to 2005 levels. This national commitment mandates the establishment of baselines for carbon footprint indicators and measures, including those at institutions of higher education, in the public sector, as a basis of evidence-based emission reduction and accountability. Organizational carbon footprints are usually classified into Scope 1 (direct emissions), Scope 2 (purchased energy emissions) and Scope 3 (other indirect emissions). While Scope 1 and Scope 2 emissions are most often documented in education institutions, Scope 3 emissions are not well documented, despite often being the largest share of total institutional emissions. Within the Scope 3 categories, staff commuting is a frequent and behavior-driven source of emissions strongly influenced by transport mode and travel distance. Considering that commuting is outside institutional operational control, it requires a methodology guided by activity-based estimation that merges travel data with standard emission factors (DEFRA, 2023). A baseline commuting carbon footprint is important in determining the magnitude of emissions and behavioral drivers, and in making low-carbon mobility planning decisions in institutional settings.

### *1.1 Objectives of The Study*

Several significant analytical findings emerge from this work that collectively improve institutional knowledge of Scope 3 commuting emissions. The objectives of this study are: (1) to establish a baseline carbon footprint for staff commuting to quantify Scope 3 mobility-related emissions in the institutional setting and (2) to build a framework linking baseline measurement to support policy planning institutional low carbon strategies.

## 2. Literature Review

Carbon footprint development at the baseline is thus increasingly recognized as a fundamental element of climate planning at institutions. In the absence of baseline quantification, institutions lack the empirical base necessary for evaluating mitigation strategies and monitoring emissions reduction (Filho et al., 2019).

### *2.1 Campus Carbon Footprint*

Campus carbon footprint analysis among Malaysian university campuses has shown that transportation emissions account for a large segment of institutions' carbon inventories and provide a baseline against which universities can base their target setting. With university green infrastructure in mind as well as environmental monitoring purposes, carbon footprint assessment has arisen as an indispensable tool for universities to find out if things are going well and provide guidance over how sustainable their institutions should operate. Turning organizational activities into greenhouse gas emissions provides the basis for universities to set baselines, monitor performance, and take decisions about decarbonization at strategic level (Larsen et al., 2013 & Robinson et al., 2019). The first study on sustainability at the campus was limited to operational energy consumption but recent developments highlight the role of indirect emissions such as mobility and behavioral actions (Alshuwaikhat & Abubakar, 2008 & Lozano et al., 2015).

### *2.2 Scope 3 Emissions and Institutional Commuting*

Greenhouse gas emissions from organizations are typically based on the concept of Scope 1, Scope 2, and Scope 3 and include indirect emissions when the source of the emission comes from organizational activities where the operational control is not directly involved (Wiedmann & Minx, 2008). From Scope 3 categories, commuting is one of the largest contributors in relation to institutional emissions thanks to the daily travel and the use of private vehicles (Townsend & Barrett, 2015). Empirical campus carbon footprint analyses frequently find commuting as one of the largest indirect emissions sources, particularly in commuter-based institutions where campuses are generally dependent on students using individual transport (Larsen et al., 2013). Similarly, Malaysian university campus studies show that transportation contributes a measurable share of university emissions alongside energy consumption, which indicates a need for detailed mobility assessment.

### *2.3 Driving Factors of Mobility Emissions of Commuting Emissions*

Emission reduction studies from transportation suggest that the travel distance and mode of transport are the chief contributors to commuting emissions. Dependence on private vehicles is very strongly correlated with greater emissions intensity than public or shared transport options (Chapman, 2007). Distance serves as a multiplicative driver, reflecting a proportional increase of emissions as travel length increases, regardless of the mode of transportation. Sustainable mobility research underscores commuting emissions as being reflective of interactions among individual behavior, spatial layout and institutional context (Banister, 2008). The Malaysian campus sustainability literature shows that transport behavior contributes to the profiles of institutional carbon footprints as well as the ways to mitigate them.

### *2.4 Policy Implications of the Baseline Carbon Footprint*

A growing literature on baseline carbon footprint development takes a diagnostic perspective that links emissions measurement to policies' construction. Instead of being only a description exercise, baseline assessment allows structural drivers of emissions and helps to priorities intervention opportunities (Lozano et al., 2015). The sustainability governance literature indicates that targeting high-impact behavioral segments allows us to mitigate them more effectively than applying more uniform interventions. In Malaysia, campus initiatives also point out that quantification of emissions sources can be used to guide the development of targeted mitigation strategies and institutional decarbonization planning.

## 3. Methodology

This study applies an activity-based estimation approach to quantify baseline Scope 3 staff commuting emissions.

### *3.1 Research Design*

Fig. 1 presents the workflow, which follows greenhouse gas inventory principles where emissions are calculated from the combination of staff commuting activity data and emission factors. The boundary for the analysis is staff commuting and it depends on self-reported one-way distance and primary transport mode for the core activity data.

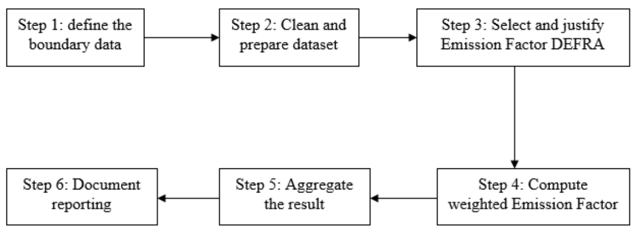


Fig. 1: Workflow for estimating baseline Scope 3 staff commuting emissions

### *3.2 Scope Boundary and Scope Definition*

This study is limited here to Scope 3 emissions caused by the commuting for the employees with respect to commuting of employees from residence to campus. Scope 3 emissions are indirect emissions resulting from organizational operations but not directly for direct operational control and are therefore outside control. In this study, commuting emissions are defined as the emissions of day-by-day travel to and from the institution. The system boundary extends only to routine commuting and does not apply to business, student or logistics-related transport. This limit serves as a mechanism for rigorous analysis and is in keeping with institutional practices in the past that have centered around measuring institutional carbon footprint.

### *3.3 Data Collection*

It was cleaned to ensure valid estimation by eliminating or flagging missing values and examining extremes, leading to a total of 249 eligible respondents to analyze. Mode-specific emission factors were selected from UK Government Greenhouse Gas Conversion Factors for Company Reporting: DEFRA and DESNZ (2023), taking representative average passenger travel values for cars (0.171 $kgCO_2e/km$), motorcycles (0.103 $kgCO_2e/km$) and taxi/e-hailing (0.180 $kgCO_2e/km$). The primary data was obtained via a structured questionnaire based on staff questionnaire. The survey collected self-reported information about commuting behavior, including: (i) main means (mode of transport); (ii) one-way distance; (iii) frequency commuting.

### *3.4 Carbon Footprint Calculation*

Commuting emissions were estimated using an activity-based calculation approach that links travel distance with transport-specific emission factors. Emissions for each respondent were calculated using equation (1).

$$Ei = Di \times EF_m \tag{1}$$

Where $Ei$ is emissions for respondent i ($kgCO_2e$), $Di$ is commuting distance (km) and $EF_m$ is emission factor for transport mode m ($kgCO_2e/km$).

Emission factors were derived from internationally recognized sources, including IPCC guidelines and DEFRA conversion factors, which provide standardized emissions coefficients for different transport modes. This ensures methodological consistency and comparability with existing carbon footprint research. Individual emissions were aggregated to estimate total institutional commuting emissions and average emissions per respondent.

$$EF_w = \frac{\sum m \, (n_m \times EF_m)}{\sum m \, n_m} \tag{2}$$

$$EF_w = \frac{(192 \, x \, 0.171) + (53 \times 0.103) + 4 \, x \, 0.180}{249}$$

Because commuting mode was available in this case, an aggregated count rather than individual mode distance pairing, a weighted emission factor and mean emission was calculated based on the distribution of commuting modes as in equation (3).

$$E_{baseline} = \sum (D_{roundtrip} \times EF_{weighted}) \tag{3}$$

$$E_{baseline} = 5{,}896.4 \times 0.156 = 923.8 \, kg \, CO2e/day$$

$$E_{mean} = E_{baseline} = 9.23.8 = 3.71 \, kgCO2e/person/day$$

### *3.5 Distribution of Emissions Analysis*

Besides baseline estimation, the analyses of commuting emissions dispersion mapping for each respondent also shows data to determine the heterogeneity and concentration of emissions. A distributional analysis was carried out to compare individual emission values for each commuter and to analyze the contribution of high-impact commuters to the total volume of emissions. This analytical step facilitates finding emissions concentrations and interprets intervention leverage for institutional mobility policy.

### *3.6 Data Analysis*

Summary statistics summarizing commuting characteristics and emissions outcomes were analyzed using descriptive statistical approaches. Main indicators; (i) Total baseline emissions; (ii) Mean emissions per respondent; (iii) Emissions by transport mode; (iv) Emissions by distance category. This combines baseline estimation with a distribution analysis as a means of enabling the study to transcend measurement of emissions to include a more policy-relevant interpretation.

### *3.7 Ethical Considerations*

Data on individual-level information was only analyzed for emissions estimation and distribution analysis, and no personally identifiable information was shared.

### *3.8 Assumptions*

Several assumptions were taken into consideration to have a reliable baseline estimation includes (i) Commuting distances were first assumed to be usual daily travel behavior for the survey period taken for granted; (ii) travel was assumed to be round-trip commuting, doubling the reported one-way distance; (iii) normal average emission factors were utilized to account for passenger travel instead of individual vehicle types; (iv) where mode distance linkage on an individual basis was not available, it was assumed distance distribution does not systematically differ across modes of transport and thus, a weighted emission factor could be used. These assumptions align with usual baseline estimations of the corporate carbon footprints in studies and allow for transparent reporting.

### 3.9 *Limitation*

The cross-sectional survey design reflects commuting behavior at only one point in time and may be seasonal dependent. Emission factors are average and thus lack vehicle-specific details. However, this approach is still suitable for both baseline estimation and for institutional planning purposes, if the aim is to find structural patterns and policy leverage rather than for specific individual emissions.

## 4. Result

The results show that staff commuting creates a measurable Scope 3 emissions baseline driven primarily by dependence on private vehicle use and distances traveled. Car commuting leads the mobility profile, while longer commute distances account for a disproportionately large share of total emissions. The baseline estimation provides transparent institutional references to determine the magnitude of emissions and target areas as well as priority for low-carbon mobility interventions.

### *4.1 Mode Commute*

The analysis in Table 1 shows a high concentration of people using private vehicles to commute. 77.1% use cars, 21.3% use motorcycles, and 1.6% use e-hailing. This pattern validates the occurrence of private motorized transport in the institutional commuting profile.

Table 1: Mode commute

| **Mode** | **n** | **percentage** |
|---|---|---|
| Car | 192 | 77.10% |
| Motorcycle | 53 | 21.30% |
| E-hailing | 4 | 1.60% |
| Total | 249 | 100% |

### *4.2 Distribution of Commuting Distance*

249 personnel were included in the analysis as in Table 2. The commuting distance distribution shows that most of the participants cover medium distances, running from 5 km to 15 km (50.2%). Short-distance (<5 km) commuters constitute 25.7%; long-distance (>15 km) commuters occupy 24.1%. This distribution indicates significant differences in commuting behavior, indicating that contributions to emissions are likely to spread more widely among distance groups.

Table 2: Distribution of commuting distance

| **Distance category** | **n** | **percentage** |
|---|---|---|
| <5 km | 64 | 25.70% |
| 5–15 km | 125 | 50.20% |
| >15 km | 60 | 24.10% |

### *4.3 Activity Baseline of Staffs Commuting Emission*

Emission data was from internationally recognized conversion data sets. Transport emission coefficients are provided by the UK Government Greenhouse Gas Conversion Factors for Company Reporting (DEFRA, 2023) and are standardized emission factors for passenger travel by transport modality. The computation approach is based on the activity-based estimation framework as recommended in the IPCC (2006; IPCC, 2019) greenhouse gas inventory guide. Using representative average passenger travel emission factors: 0.17 kg$CO_2$e per km for cars, 0.10 kg$CO_2$e per km for motorcycles and 0.18 kg$CO_2$e per km for taxi/e-hailing services.

Estimation through activity-based mode-specific factors of emissions showed that a baseline Scope 3 staff commuting emissions were about 923.8 kg$CO_2$e per day (n=249). The mean emission for commuting per respondent was 3.71 kg$CO_2$e per person per day. Commuting distance is heavily variable, with an average one-way (11.84 km) and median (7.0 km) commuting distance that suggests a right-skewed commuting profile that accounts for a sizeable part of the total emissions for more distant commuters.

Table 3: Activity base of staff commuting emission

| Indicator | Value |
| --- | --- |
| Total one-way distance, Σ km | 2,948.20 |
| Total round-trip distance, Σ km/day | 5,896.40 |
| Weighted emission factor, $kgCO_2e/km$ | 0.1567 |
| Baseline commuting emissions, $kgCO_2e/day$ | 923.8 |
| Mean emissions, $kgCO_2e/person/day$ | 3.71 |

## 5. Discussion

Our findings suggest that staff commuting is a prominent Scope 3 emissions source largely due to transport reliance and travel distance dependency. The heavy reliance on private cars confirms that emissions related to commuting are behavior-driven and shaped by mobility patterns rather than the use of operational energy. Baseline estimation reveals that structural characteristics of emissions are driven by longer-distance commuters, suggesting uneven emissions distribution and behavioral drivers in institutional carbon footprints. This highlight specific points of leverage on which targeted mitigation interventions can be implemented such as modal shift, carpooling, and mobility management initiatives. These findings strengthen the usefulness of the activity-based estimation frameworks by translating commuting behavior into institutional emission indicators. In practical terms, the baseline acts as a diagnostic instrument for monitoring, prioritizing interventions, and informing evidence-based low-carbon transport policy planning.

## 6. Conclusion

This study develops a baseline Scope 3 carbon footprint of staff commuting at Politeknik Sultan Abdul Halim Mu'adzam Shah using DEFRA emission factor approach. By quantifying commuting emissions and examining institution staff commute, this study provides empirical evidence to support targeted mitigation strategies and evidence-based low-carbon transport policy development within institutional governance. To overcome these barriers within the future, institutional policies can focus on promoting mobility-focused mitigation including encouraging alternative modes of transportation, reducing reliance on single-occupancy vehicles and incorporating emissions related to commuting into broader sustainability planning.

Commuting carbon baseline can be established and updated that allows higher education institutions to shift from general commitments to sustainability towards more organized low-carbon governance based on objective evidence. And last, this research sets a framework baseline measurement and provides a model for supporting planning for institutional low carbon plan by showing how the assessment of institution carbon footprint can inform decision-making processes.

**Author Contributions:** The research study was carried out successfully with contributions from all authors.

**Conflicts of Interest:** The authors declare no conflict of interest.

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