EMISSION FREE EUROPEAN UNIVERSITIES

Strategic Development of Students' Sustainability Competences in Engineering Sciences

Work Package #4

University practices assessment and continuous improvement – keeping on track to emission neutrality

Part B – Activity 4.2: Development and Testing Process for the Built-in Software to Compute CO2e based on Students and Staff Transportation Habits

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About this Publication

This publication forms part of *Work Package 4 – University Practices Assessment and Continuous Improvement – Keeping on Track to Emission Neutrality* of the Erasmus+ Strategic Partnership project *Emission Free European Universities (EFEU)*. The EFEU project aims to strengthen sustainability competences in higher education and support the transition of European universities toward climate neutrality through evidence-based, transferable, and inclusive approaches. Within this framework, Work Package 4 focuses on identifying, analysing, and improving institutional practices related to mobility, teaching, and campus operations that influence universities' greenhouse gas emissions.

The purpose of this report is to present the methodology, implementation process, and key results of *Activity 4.2: Development and Testing of the CO_2 Emissions Computation Model*. This activity represents a central step in operationalising the objectives of WP4 by developing a digital tool capable of quantifying carbon emissions generated by students' and staff mobility habits. Building on empirical data from the EFEU Mobility Survey (Part A) and methodological foundations defined in previous project stages, the software provides a transparent and replicable model for calculating CO_2e emissions in higher education contexts. The report details the conceptual design, technical development, and validation process of the built-in software, illustrating how it transforms mobility data into actionable sustainability indicators.

By linking mobility analysis, data-driven modelling, and user engagement, this publication contributes to WP4's broader objective of supporting continuous improvement in university sustainability practices. Together with other WP4 outputs—including the *Mobility Survey Report* (Part A), *Development and Testing Model* (Part B), *Carbon Footprint of Teaching and Calculator* (Part C), *Sustainable Mobility Workshops* (Part D), and the *Guide of Good Sustainable Mobility Practices* (Part E)—this report provides practical insights and transferable tools for higher education institutions. It exemplifies the EFEU consortium's commitment to integrating research, innovation, and education in pursuit of emission-free European universities.

The online version of this report can be obtained from the project's website:
https://www.dhbw-stuttgart.de/efeu

1 Introduction

Greenhouse gas emissions (GHG) are a widely adopted benchmark for assessing the environmental performance of Higher Education Institutions, which are well placed to take on a leadership role in fighting climate change due to their role in educating future engineers. Furthermore, these educational institutions have a dual role on both advancing scientific knowledge on sustainability while simultaneously reducing the environmental impacts of their own operations by planning and implementing policies to reduce them (Deda et al., 2025). Among the many activities contributing to institutional emissions, staff and student commuting stands out as a critical source of GHG , often accounting for a substantial share of total university-related CO_2 output (Lin et al., 2024; Perez-Lopez et al., 2021).

Research has consistently shown that mobility patterns associated with academic life, such as frequency of on-campus presence, travel distances, and modal choices, play a decisive role in shaping universities' environmental impacts. Mobility emissions can be reduced by improving access to and promoting the use of public transportation, biking, or walking. The teaching method can also have a significant impact on the number of students and staff travel. In fact, scheduling classes five or four days per week can make a huge impact on GGE. Studies consistently show that mobility patterns associated with academic life, such as frequency of on-campus presence, commuting distances, and modal choices, are decisive in shaping universities' environmental impacts (Kiehle et al., 2023). Transport-related GHG emissions are frequently highlighted as hotspots in HEI carbon accounting and, in several institutions, surpass direct emissions from energy consumption (Helmers et al., 2021; Perez-Lopez et al., 2021).

Several methodological approaches have been developed to address these challenges. The case study of the University of A Coruña in Spain by Perez-López et al. (2021) applied an ecological footprint methodology to assess commuting emissions, revealing the impact of transport mode distribution on overall institutional sustainability. Lin et al. (2024), analyzing Zhejiang Ocean University in China, applied emission factor methodologies to assess institutional CO_2 emissions, further confirming that commuting and mobility behaviours represent an essential dimension of university sustainability strategies.

For the EFEU project, a specifically tailored CO_2e computation model software was created. The developed tool captures key parameters such as commuting frequency,

distance, and modal choice. These inputs are converted into CO_2e emissions using internationally recognized emission factors, aligned with best practices for higher education sustainability reporting. The software is simple, user-friendly, and relevant information is transmitted to the users, which can be crucial to accelerate a change in mobility habits.

The software is based on a questionnaire with short questions that quickly generates results for the participants. Importantly, results are presented not only in numerical terms but also through relatable equivalents (e.g., comparing emissions to medium-haul flights), thereby contextualizing impacts and encouraging reflection.

By integrating simplicity, transparency, and behavioural engagement, the EFEU computation model contributes to ongoing international efforts to standardize emissions assessment in universities while also functioning as an awareness-raising instrument for individual users. Its dual role, as both a reporting tool for institutions and a behavioural intervention for students and staff, reinforces its potential to support the transition of HEIs towards low-carbon mobility and broader climate neutrality goals.

2 CO_2 Emissions Calculation Software Development - A Multi-Step Process

2.1 Process Phases

Activity 4.2: Phase 1 – Conceptual and Methodological Design

The first phase focused on defining the theoretical and methodological foundations. It included:

- **Problem definition and requirements elicitation:** establishing the software's purpose—to link teaching and mobility habits to CO_2 emissions—and specifying functional (calculation logic, outputs) and non-functional (security, accessibility) requirements.
- **Standards alignment:** adopting internationally recognised accounting principles (GHG Protocol, ISO 14064) and determining system boundaries, in-scope gases, and reporting conventions.
- **Data governance:** cataloguing input datasets (survey results, transport factors) and defining data quality attributes such as accuracy, timeliness, and comparability.
- **Emission factor strategy:** selecting authoritative factors for each transport category and documenting their provenance and version control.
- **Model architecture:** designing a modular structure that separates ingestion, validation, computation, and reporting layers, enabling straightforward updates and future scalability.

  An early **prototype** was released to test workflows and terminology with end users, generating feedback that informed both the interface and the underlying algorithmic design.
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Activity 4.3: Phase 2 – Technical Development, Testing, and Implementation

The second phase covered software engineering, pilot validation, and deployment. The calculation algorithms were implemented as side-effect-free Python functions, ensuring transparency and reproducibility. Extensive unit and property-based testing verified that all outputs remained dimensionally consistent and within expected ranges. Automated pipelines managed data ingestion, unit conversions, and error handling, while audit trails recorded every computation, emission factor version, and user action

to facilitate verification. Sensitivity and uncertainty analyses assessed the robustness of outputs against variations in user inputs and emission coefficients.

Performance and scalability tests confirmed the system's capacity to process large volumes of simultaneous user sessions without degradation. Security measures included encryption, role-based access, and data minimisation to comply with GDPR principles.

After successful pilot deployment with real data from the four partner universities, the tool was released publicly with full **documentation, user guidance, and API references**, ensuring interoperability with institutional sustainability dashboards. Continuous feedback mechanisms and semantic versioning allow ongoing updates of emission factors and methodological refinements.

2.2 Holistic Overview of the Development Workflow

The EFEU CO_2 Emissions Calculation Software was developed to quantify greenhouse gas emissions arising from students' and staff mobility, thereby enabling universities to assess, model, and reduce their institutional carbon footprint. The process followed a structured, multi-step methodology—from conceptual design to pilot implementation—combining scientific rigor, transparency, and user accessibility.

The development began with the definition of goals and system boundaries in accordance with the *Greenhouse Gas (GHG) Protocol* and ISO-aligned practices. These standards ensured the inclusion of all relevant emission sources (Scope 3 – commuting-related emissions) and the comparability of results across higher education institutions. The objective was to deliver an open, transparent, and reproducible model that links travel behaviour with environmental impact while functioning as both a reporting and awareness-raising tool.

The software translates user-provided activity data—such as commuting frequency, travel distance, and transport mode—into carbon dioxide equivalents (CO_2e) using established emission factors. These factors, derived from WP2 "State of the Art Analysis," were validated against authoritative datasets (e.g., UBA, DEFRA) and include transport-specific coefficients (e.g., 0.27 kg CO_2e/km for petrol cars, 0.10 for buses, 0.03 for trams).

A modular architecture was implemented using the **Django framework** (Python), comprising data ingestion, validation, computation, and visualization layers. Each module operates independently, ensuring maintainability, scalability, and

transparency. User input is processed through a short nine-question interface, with results instantly displayed as both numerical outputs and relatable equivalents—for instance, equating annual commuting emissions to the CO_2e of a medium-haul flight. This dual format enhances user understanding and encourages behavioural change toward sustainable transport modes.

Testing cycles were conducted iteratively across design, technical validation, and behavioural evaluation phases. Benchmark datasets and manually verified spreadsheets served as reference points to ensure numerical precision. Each calculation routine underwent unit testing and sensitivity analysis to confirm internal consistency and to identify parameters exerting the greatest influence on final results (e.g., weekly commute days, transport mode).

Following pilot deployment, the tool was integrated into the public platform https://efeu.cdrsp.ipleiria.pt, accessible in both online and offline formats. Initial usage data recorded more than **500 valid user interactions** within the first ten weeks, confirming strong usability and engagement across partner institutions. The model thus evolved from a technical deliverable to an interactive educational resource supporting data-driven mobility planning and emission reduction in higher education.

2.3 Detailed Overview of the Development Workflow

The multi-step development of the CO_2 Computation Software followed a structured 20-step engineering and governance process, grouped into the beforementioned two overarching stages:

Stage 1/Phase 1 – Design, Development, and Testing

This phase translated the conceptual framework into a fully operational prototype.

1. **Problem Framing & Goal Definition:** Scope, objectives, and success criteria were defined, establishing measurable targets for transparency, accuracy, and usability.
2. **Standards Alignment & Boundaries:** Methodology aligned with the GHG Protocol and ISO standards, defining gases, timeframes, and life-cycle boundaries.
3. **Requirements Elicitation:** Functional and non-functional requirements were identified through workshops with domain experts and end users.

4. **Data Inventory & Governance:** Activity data, emission factors, and metadata were catalogued; quality dimensions (accuracy, completeness, timeliness) were set.
5. **Methodology & Emission Factor Strategy:** Each transport category was linked to authoritative emission factors with documented provenance.
6. **Data Model & Architecture Design:** A modular architecture separated data ingestion, validation, computation, and reporting layers, ensuring maintainability and scalability.
7. **Prototype & Rapid Feedback Loops:** A clickable prototype was tested with users, generating iterative refinements in usability and terminology.
8. **Validation Pipelines:** ETL processes applied schema checks, unit conversions, and error handling; all data transformations were logged for traceability.
9. **Algorithm Implementation & Unit Testing:** Core calculations were implemented as independent Python functions, validated through automated tests and reference spreadsheets.
10. **Benchmark & Scenario Validation:** Model outputs were cross-checked against verified datasets to ensure reliability within pre-defined tolerances.
11. **Uncertainty & Sensitivity Analysis:** Input quality ratings and parameter sensitivities were assessed to prioritise data improvement.
12. **Performance & Scalability Testing:** Load tests ensured efficient processing under high user volumes.
13. **Security & Compliance:** Encryption, access control, and data minimisation guaranteed GDPR conformity.
14. **Transparency & Auditability:** Full traceability of emission factors, formula versions, and user interactions ensured methodological reproducibility.
15. **User Experience & Accessibility:** Results visualisation and export functions (CSV, XLSX, PDF) supported inclusive, transparent reporting.

Stage 2/Phase 2 – Governance, Deployment, and Continuous Improvement

This phase ensured institutional validation, release management, and iterative optimisation.

16. **Stakeholder Review:** Governance gates assessed methodological soundness, data integrity, and test results before pilot release.
17. **Pilot Deployment:** Controlled testing under real data conditions validated workflows and performance metrics.
18. **Documentation & Training:** Comprehensive manuals, API references, and tutorials supported adoption and knowledge transfer.
19. **Release Management:** Versioning and change logs tracked updates in emission factors and methodological refinements.
20. **Continuous Improvement:** A feedback mechanism, analytics monitoring, and periodic factor updates ensured long-term accuracy and user engagement.

This detailed workflow provided a robust structure integrating **software engineering, environmental science, and user-centred design**, ensuring that the final product meets both academic and operational standards required by Erasmus+ and the European Commission.

3 The EFEU CO2e Computation Software

The built-in software computes the amount of CO2e produced by daily mobility habits. The software is available online (https://efeu.cdrsp.ipleiria.pt) and has only a few questions (9). The idea behind the software is simplicity, computation accuracy and impactful answers with the goal of changing mentalities and mobility habits. The obtained results can help University departments and their directors implement measures in the pedagogical activities.

The questions were originally designed for university students and staff, reflecting the main objective of the EFEU project. However, the software is also suitable for anyone outside the University context, as it can be easily applied to everyday mobility habits. The first page of the built-in software provides an information section, where users are introduced to the EFEU project and its objectives. At this stage, users may optionally provide their country and email address, but this step can also be skipped. The software is fully functional without the need to share any personal information, ensuring accessibility and privacy. The second page contains nine questions focusing on mobility habits, particularly the daily commute from home to the University:

1. How many days in the week do you commute to university?
2. How many weeks per year do you commute to university?
3. Which type of car do you use?
4. How many km by car? (one way trip)
5. How many km by motorcycle? (one way trip)
6. How many km by bus? (one way trip)
7. How many km by tram/metro? (one way trip)
8. How many km by train? (one way trip)
9. How many km by scooter? (one way trip)

The software was created in Django, which is a platform of Python programming language.

The first question only accepts integer numbers between 0 and 7. Similar to the first question, the second question accepts an integer between 0 and 52. In the third question participants could choose from five options: None, Diesel, Petrol, Hybrid or Electric (see Figure 1).

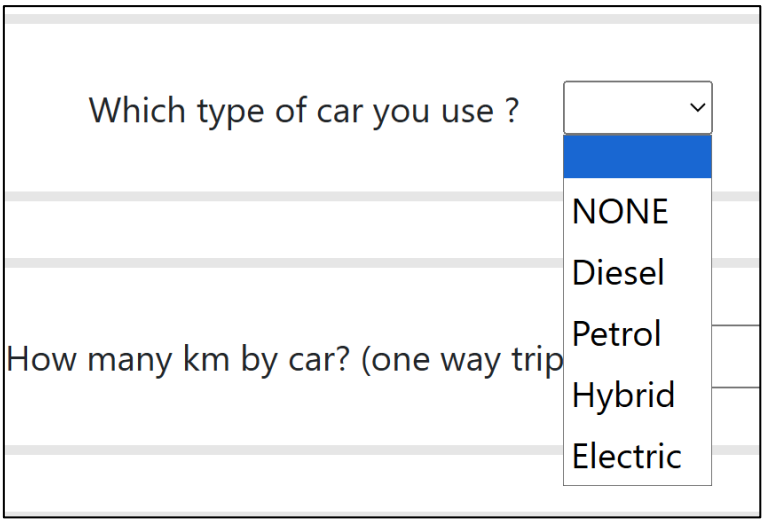

Figure 1: Response options for the question "Which type of car do you use?"

In the following six questions, users were asked to indicate the number of kilometres for a one-way trip using different transport modes: car, motorcycle, bus, tram/metro, train, and scooter. Responses to these questions may be provided as real (non-integer) numbers.

Each transport type has its own associated GGE. The values used per transport type are based on Work package n°2 - State of the Art Analysis. In this Work Package the EFEU Carbon Footprint calculation tool was developed and it is available in the project website: https://www.dhbw-stuttgart.de/forschung-transfer/technik/projekte/efeu/. Thus, in

Table 1, CO2e emissions per km for all types of transport are presented.

Table 1: CO2e emissions per type of transport mode

Transport Mode	kgCO2e/km
Car diesel	0.27
Car petrol	0.27
Car hybrid	0.12
Car electric	0.08
Motorcycle	0.11
Bus	0.10
Tram/metro	0.03
Train	0.04
Electric scooter/bike	0.08

These values are average values, but are accepted in the literature, as explained in the Work Package 2 report.

Using the values in

Table 1 and the answers to the questions, it is possible to compute CO2e based on mobility habits.

Therefore, when the software user presses the button “submit questionnaire” (see Figure 2), the third and last pages of the built-in software appear.

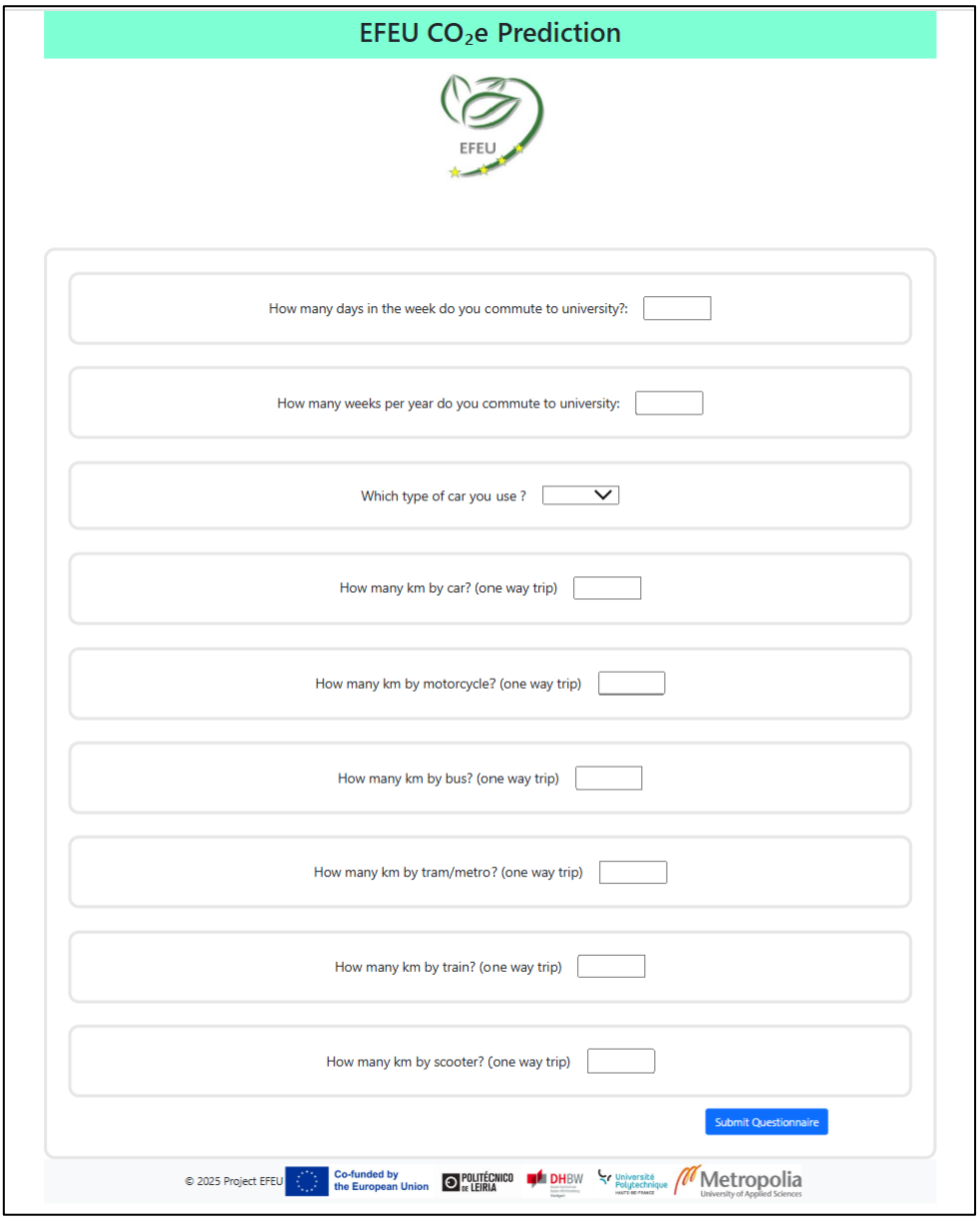

Figure 2: Overview of the nine questions in the built-in software

As mentioned before, the built-in software was developed on the Django platform. Django is a web framework written in Python. Django can be used to create web pages with computational capabilities.

Figure 3 shows as example a part of the EFEU built-in software.

```python
from django.shortcuts import render,redirect
from django.contrib import messages
from .models import Participant, Questionnaire
import pycountry
# Create your views here.


CARBON_FACTORS = {
    'petrol':0.27,
    'diesel': 0.27,
    'hybrid': 0.12,
    'eletric': 0.08,
    'nan': 0.0,
}

def home(request):
    countries = [(country.name, country.name) for country in pycountry.countries]
    if request.method == 'POST':
        email = request.POST.get('email')
        pais = request.POST.get('pais')

        participant, created = Participant.objects.get_or_create(
            email=email,
            defaults={'pais': pais}
        )

        request.session['participant_id'] = participant.id

        return redirect('questionnaire')

    return render(request, 'core/home.html',{'countries':countries})


```

Figure 3: Example of Django programming - EFEU built-in software

3 Results

The third page of the built-in software presents the results. Based on the data in table 1 and the answers to the nine questions, the built-in software computes the amount of CO2e produced by daily mobility habits.

For instance, in the EFEU Mobility Survey (see part A) the average number of km per trip that a student takes by car is 19 km. For example, consider a student who travels 19 km per trip, 5 days per week, 35 weeks per year, in a diesel car. The results presented in Figure 4, confirm that this student is responsible for 10.26 kgCO2e per day, 5 days a week. These values, when considered in isolation, may appear to have limited significance. However, to provide perspective, a comparative analysis was conducted using the carbon footprint of a one-way medium-haul European flight on an Airbus A320 aircraft. The results indicate that, in less than six weeks, a single student generates an amount of CO_2e equivalent to that produced by one passenger on such a flight. Extending this to 12 weeks, which is less than a full semester, the emissions correspond to a round trip, such as Stuttgart–Athens or Lisbon–Paris.

This student's mobility pattern is based on a conventional schedule of five days per week of onsite classes. To assess the effect of a reduced schedule, a scenario of four days of attendance per week was considered. The output of the calculation tool also provides this adjusted value. In this case, over approximately 30 weeks, corresponding to nearly one academic year, the reduction in CO_2e emissions achieved was equivalent to the footprint of a one-way medium-haul European flight on an Airbus A320.

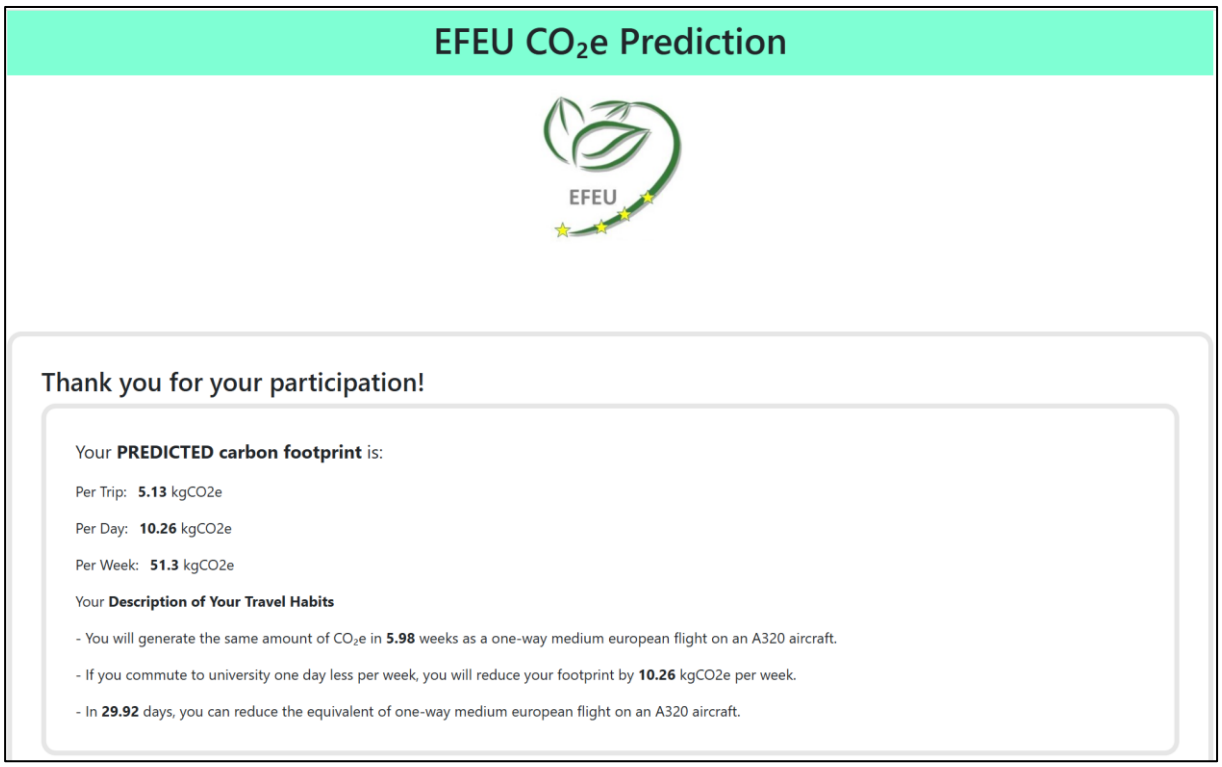

Figure 4: Sample student (5 days/week, 19 km/ trip, diesel car)

In the second scenario, the student commutes four days per week over the same 35 weeks per year but uses the tram instead of a car. The travel distance remained unchanged at 19 km per trip. As illustrated in Figure 5, this commuting pattern resulted in daily emissions of only 1.14 $kgCO_2e$. Under these conditions, it would take approximately 67.3 weeks (more than one year) to generate emissions equivalent to a one-way medium-haul European flight on an Airbus A320.

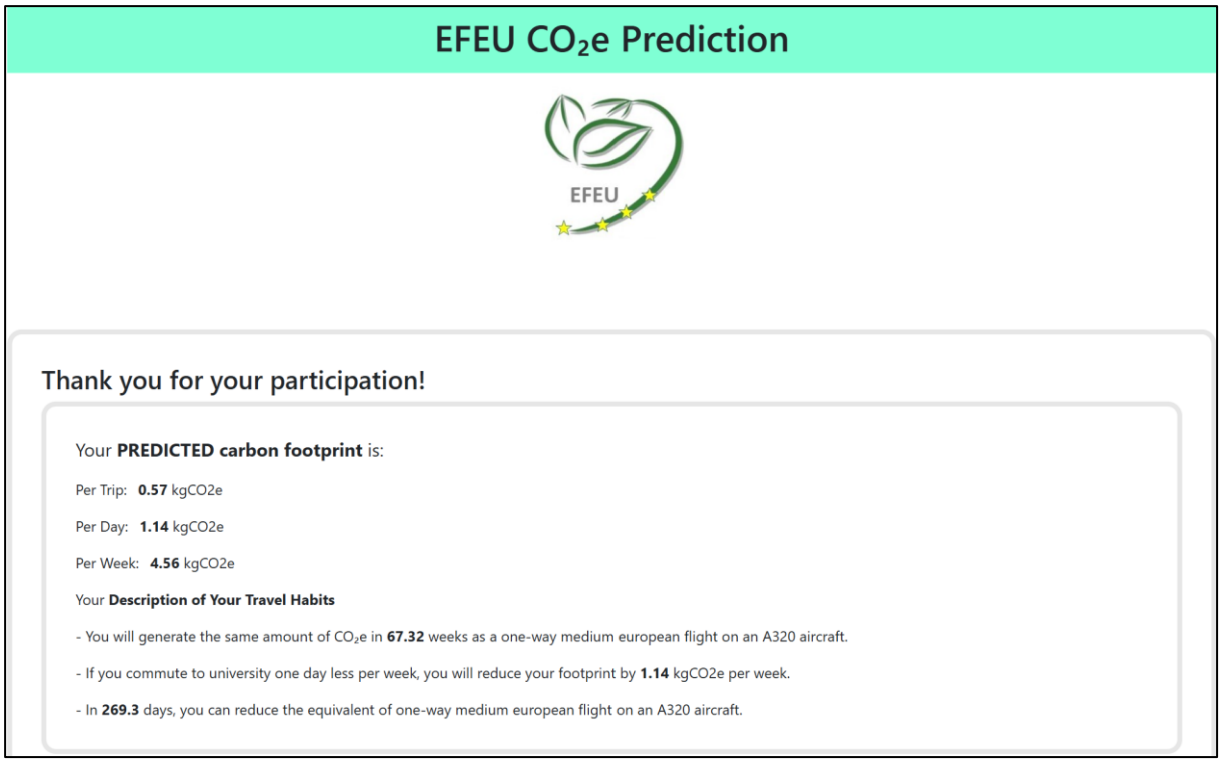

Figure 5: Sample student (4 days/week, 19 km/trip, tram)

Results are presented in a simple format, but also in a clear mode. Users can change the answers to the 9 questions in order to understand better how mobility habits can influence GGE.

4 Discussion

A built-in software that computes the amount of CO2e produced by daily mobility habits was developed within the scope of the EFEU project. The software is available online (https://efeu.cdrsp.ipleiria.pt).

The built-in software was created using Django, which is a Python library.

With this built-in software, it is possible to observe the impact of mobility habits on the GGE. This built-in software was developed in the scope of EFEU project. Accordingly, the first two questions are specifically related to university commuting.

Despite its versatility, the software also has limitations. While its generic design allows the substitution of *university* with *workplace*, enabling any individual to evaluate the impact of personal mobility habits on global CO_2e emissions, it provides only a simplified estimation. The results should therefore be interpreted as indicative values, useful for raising awareness and promoting behavioral change, but not as precise carbon footprint assessments. The results obtained from the built-in software, together with the mobility report, can provide valuable evidence to support institutional decision making. For instance, university directors may consider reducing the number of in-person class days from five to four, which could significantly decrease mobility-related emissions from students and staff members. Beyond academic settings, the software also has potential applications for municipalities, where improvements in public transportation—such as optimized timetables, extended routes, and increased service quality—can strongly influence greenhouse gas emissions (GGE) by encouraging the broader adoption of sustainable mobility options. Developed within the scope of the EFEU project, this tool extends beyond its initial framework and has the potential to inform and shape future public policies on mobility and sustainability.

However, this software does not take into account the additional CO2e emissions that are generated within the homes of the students if classes are switched from in-person to online classes. A deep investigation on this matter will be given in part C of this report.

5 Relevance, Impact, and Transferability

The CO_2 Computation Software represents a pivotal achievement of the EFEU project's Work Package 4. It provides higher education institutions with a scientifically grounded yet accessible means to monitor and reduce commuting-related emissions—one of the largest contributors to Scope 3 university footprints. Beyond quantification, the tool fosters behavioural change by transforming abstract emission data into understandable equivalents, thereby raising awareness among students and staff.

The software's modular architecture ensures its **transferability** to other universities and public institutions. It can be adapted to local datasets or integrated into digital sustainability platforms for ongoing monitoring and reporting. Moreover, its scenario analysis capability supports institutional decision-making—illustrating, for example, how reducing on-campus attendance from five to four days per week yields savings comparable to one medium-haul flight per student over a three-year degree.

Aligned with **Erasmus+ priorities** of sustainability, digitalisation, and innovation, the tool contributes directly to the **European Green Deal** and the **UN Sustainable Development Goals (SDG 11 and SDG 13)**. By combining methodological rigor with educational outreach, it strengthens universities' capacity to lead the transition toward climate-neutral operations and offers a replicable model for sustainable transformation across Europe.

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