# The Carbon Footprint of Online vs. In-Person Learning in Higher Education

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*Abstract: Our task focused on three main areas: determining the carbon footprint of university education through a university campus and identifying possible areas for emission reduction, investigating the impact of online education on the carbon footprint, identifying international practice, and developing a survey methodology to ensure comparability of results. After a comprehensive literature review, a functional unit and analysis method were defined, considering the areas responsible for carbon emissions on university campuses by scope and category. After determining the carbon footprint values of the present and a hypothetical hybrid solution, an enumeration of possible decarbonization solutions was outlined, as a conclusion of this research.*

*Keywords: higher education; carbon footprint; decarbonization; digitalization*

# 1 Introduction

The main characteristics of higher education include advanced academic learning, critical thinking development, and specialized skill acquisition in a diverse and research-oriented environment.

At the same time, universities are also required to respond to new requirements, such as the rapid accumulation of scientific knowledge, an ever-expanding number of students, the changing needs of the economy, the increasing use of online learning, and the possibilities of using artificial intelligence. [1] Universities, as centers of intellectual life and educators of the next generation of intellectuals, have a responsibility to lead by example in tackling the major societal issues of our time. This includes understanding human impacts on our environment, finding ways to reduce them, and providing students with environmental education. [2]

The COVID-19 epidemic showed that, if necessary, higher education could quickly switch to online mode. At the same time, the rapid switch to online education posed several challenges [3] [4], including:

- Educators had to quickly adapt their teaching methods and materials to suit the online format, often requiring new skills and approaches.
- Keeping students engaged and motivated in a remote setting was challenging, as physical separation from peers and instructors could lead to isolation and reduced motivation.
- Faculty and students needed training and ongoing support to navigate online platforms and tools effectively, which strained institutional resources [5].
- Some subjects and courses, such as laboratory practices, were less suited to online delivery, necessitating adjustments or alternative teaching methods.

One positive effect of COVID-19 on online learning is that it accelerated the adoption of technology and innovative teaching methods, making education more flexible and accessible for many learners [6].

Our work revolves around three primary objectives:

- Assessing the carbon footprint associated with university education, specifically within a university campus, to identify potential areas for emission reduction.
- Investigating the environmental impact of the online education format and how it influences the carbon footprint.
- Gaining insight into international best practices and developing a survey methodology to ensure our results can be effectively compared with others.

Indeed, exploring the potential implementation of online methods in higher education is reasonable. This should include an assessment of the advantages and disadvantages and identifying the associated challenges that need to be addressed. It's important to note that the primary focus of this project isn't an in-depth analysis of the methodological and social aspects of online education. However, as university lecturers, we must clarify our stance upfront: we view the transition to online education as acceptable only within certain bounds. When determining the balance between online and in-person instruction, the well-being and educational interests of the students should take precedence. We must ensure that the shift does not compromise learning effectiveness and students' access to knowledge. Students must maintain their connections with peers and instructors. We should address education's economic and environmental dimensions only after considering these factors. Furthermore, we will also explore various other methods for mitigating the environmental impact and present them as part of our project.

# 2 Literature Review

## 2.1 Reviews and Bibliometric Studies

Li et al. [7] identified 238 relevant studies in the Web of Science database published in the last decade, observing a growing interest among researchers.

Based on the analyzed literature, the study found that:

- Higher education institutions have undertaken numerous initiatives to reduce their carbon footprint, including developing measurement tools and decarbonization technologies, monitoring university-related emissions, adopting clean energy, and reducing course-related emissions.
- Research in this field encompasses various assessment methods, models, and theoretical analyses, with solutions to promote sustainable consumption, transition to a low-carbon economy, sustainable procurement, eco-friendly energy use, and fostering sustainable student lifestyles.
- Less-explored areas include travel emissions, student carbon footprint reduction efforts, university building emissions, daily commutes' environmental impact, electronic equipment emissions, dormitory resident footprints, and the perceived reduction in emissions through online education.

Filho et al. [8] examined the decarbonization efforts of universities with a perspective up to 2050. Like the previous analysis, the researchers used the Web of Science (WoS) to perform bibliometric analysis. They concluded that in recent decades, carbon management and reduction have become popular research areas in higher education institutions. Measuring the carbon footprint of universities is a complex task, and the researchers concluded that it is not worth comparing the results of individual case studies, as several analysis methods and different system boundaries are used in most cases.

In addition to bibliometric research, a survey was sent to universities, which covered the participant's background, the decarbonization actions of the campus, and possible carbon footprint reduction procedures during education and research. Questionnaire results indicated that the key provisions for achieving low carbon intensity at the university level include reducing energy consumption, enhancing energy efficiency, installing solar panels, promoting campus sustainability, adopting zero-carbon building practices, and formulating Climate Action Plans [20]

The efforts to reduce carbon emissions are like what Li et al. [6] found. However, in this case, the researchers revealed a potential economic benefit associated with carbon reduction, which is still debated in some studies. The widely agreed-upon steps for reducing carbon emissions include reducing energy usage, adopting renewable energy sources, enhancing energy efficiency, and implementing power sharing.

Finally, a few points were gathered about how higher education institutions can initiate the reduction of their carbon footprint:

- Widely communicating that the reduction is not only the responsibility of the university administration but that all students and employees can contribute to the common goal.
- Presentation of the use of renewable energy, dissemination of knowledge at courses.
- Utilization and optimization of digitization opportunities to promote decarbonization.
- There is an essential need for qualified professionals in climate protection who can use their knowledge to help establish sustainable operations. Restructuring and expanding university curricula can effectively address this need.

In their study, Helmers, Chang, and Dauwels examined previous research on how universities calculate their carbon footprints [8] [9]. Their goal was to promote a consistent method and identify key factors, making it possible to compare results from different surveys and studies in the future. The study analyzed carbon footprint assessments from a total of 20 universities. Since carbon footprint calculations are optional for universities, they found that the quality of data sources is often lacking, and access can be limited. Additionally, there is no standardization in this field, which makes it challenging to compare the results of individual case studies. However, most of the assessments followed the GHG Protocol more or less [21].

They found that results were presented using various reference units, such as $CO_2$ emissions per person (students and employees), per campus area, or, in the case of a British university, per 1000 GBP of income. As a common element in most sources, the researchers observed that the most significant emission can be related to energy consumption, accounting for an average of 52.1% of emissions. This is followed by the impact of emissions related to everyday travel. The use of the water and sewage networks, the need for office supplies and chemicals, and waste management have a minor impact. The impact of meals, university events, equipment and IT equipment, and investments are often negligible due to the smaller footprint of the other categories.

Moreover, using ISO 14064 [22] or the GHG Protocol is recommended for calculating organizational footprints, but life cycle assessment offers more accuracy with a holistic approach. It covers all product stages, including production, building, disposal, and more. GHG Protocol and ISO 16064 consider it optional, so organizations often only consider the operational and use phases when calculating their carbon footprint. However, neglecting hidden environmental impacts can lead to wrong consumption, political, or investment choices in the climate change battle.

A study by Kiehle et al. [10] reviews standard guidelines for calculating carbon footprints, such as the GHG protocol, ISO 14064, and PAS standards. They concluded that:

- The choice of method depends on the study's scale. Smaller-scale cases often use Life Cycle Assessment (LCA) processes, while more extensive corporate and institutional analyses favor Environmentally Extended Input-Output Assessments (EEIOA). Different methods are chosen based on the sources of the emissions and purposes of investigation.

- Current guidelines for organizational-level carbon footprints don't suit the specific needs of higher education institutions. Universities may include fuel consumption and some direct fossil fuel emissions in scope 1 and purchased electricity, heating, water, and cooling in scope 2. The GHG Protocol is commonly used, with precise requirements for scope 1 and 2 emissions. However, scope 3 is more flexible, allowing universities to select specific non-energy emissions based on their context.

- Scope 3 often covers business travel emissions, focusing on air travel. Emissions from other modes of transport and hotels are considered less frequent. Universities also assess emissions from acquiring materials, general operations, waste management, and property maintenance.

## 2.2 Case Studies

Helmers et al. [11] also published a case study as the second part of their paper. They applied the carbon footprint calculation method to two university campuses, one in Germany and the other in Singapore. Despite the different locations and curricula, the overall result was similar: 124.5 and 126.3 kg $CO_2/m^2$ per year, including life-cycle impacts. The investigation primarily focused on buildings, but it also considered other activities like transportation, which was found to have the most significant impact.

Scope 3 emissions included non-energy-related emissions, like business trips, building maintenance, and purchases. They used an EEIOA database to calculate and multiply purchase prices by environmental impact [kg $CO_2$/€]. Items over €5,000 were spread over 5 years to account for depreciation. Information technology equipment emissions depended on lifespan and emissions per item. Paper items were calculated based on mass and emissions. Waste and restaurant services were considered in scope 2 due to energy use. Transport's impact was studied via a survey which had low participation. This included cars, public transport, walking, and cycling. For passenger vehicles, detailed data was used, including year and fuel type. Off-grid electricity effects were disregarded; only the Finnish energy mix values were used. In this university, the largest emission area can be linked to the energy sector; heating proved to be the most prominent load.

# 3 Carbon Footprint of Online vs. In-Person Education: A Case Study

We chose the Tavaszmező Street campus of Óbuda University for our analysis. It is a relatively closed unit, so the collected data can be handled more efficiently. It consists of four buildings:

- **Building A:** main building, dean's offices, offices, classrooms and laboratories. It is an old building, more than 100 years old
- **Building B:** mainly laboratories, a few classrooms and a few teachers' rooms. It is an old building, more than 100 years old
- **Building C:** faculty rooms and departmental offices. About 50 years old
- **Building G:** 3 large lecturers, small classrooms, some IT labs and teaching rooms. Newly built, approx. 15 years old

There are a canteen and a dormitory building on the campus, but it's important to note that they are not included in the analysis.

The campus primarily caters to the educational needs of two faculties: the Kandó Kálmán Faculty of Electrical Engineering and the Keleti Károly Faculty of Economics. In total, the campus accommodates 2094 full-time students, 84 of whom are international, 1259 part-time students, and 155 employees.

The analysis covers data spanning an entire year. We assumed that all activities within the campus buildings and their environmental impact are directly related to the educational mission. It's worth noting, that instructors also engage in research and development activities as part of their roles.


Figure 1
Tavaszmező Campus. In front: Building A, right: Building B, left: Building G

When presenting the results, we adhere to the recommended structure for calculating the organizational carbon footprint. However, it's important to clarify that in many cases, we did not derive the $CO_2$ emissions from typical sources for emission factors or calculators. Instead, we used life cycle inventory data, for which we employed the Ecoinvent 3.9.1 database [27] within the openLCA 2.0 software [28].

The diagram illustrating the survey's system boundaries can be found in Figure 7. It's commonly acknowledged in the literature that including Scope 1 and Scope 2 emissions is essential for the analysis, while Scope 3 emissions are often considered optional. Unfortunately, we had no choice but to exclude a few items from our analysis due to a lack of reliable data. Notably, some of these omitted items, including the embodied $CO_2$ content of the devices we purchased, could have been quite intriguing, particularly considering the limited amount of existing literature on this specific topic.

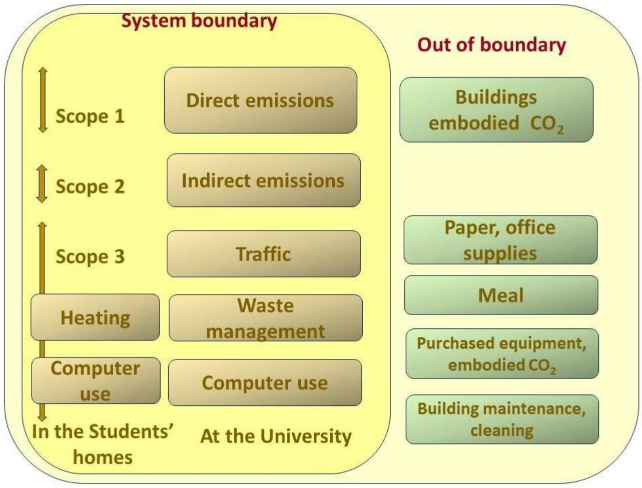


Figure 2
The system boundary of the case study

We evaluated the distinction between two modes of education: entirely in-person and a hybrid approach that includes online components. Our model for this examination operates on the assumption that the campus remains fully operational for all forms of education. This is because, given the diverse functions of the buildings, the practicality of shutting down an entire building or a portion of it is not feasible. This operational approach reflects the current practice. Our analysis involved calculating the following emissions:

**Scope 1:**

- $CO_2$ emissions from burning natural gas for heating and hot water needs
- $CO_2$ emissions from university vehicle fleet
- Coolant leakage from air conditioners

**Scope 2:**

- Electricity consumption

**Scope 3:**

- Travel, including daily commuting for instructors (4 days per week) and other staff (5 days per week), business trips made by employees, daily commuting for students (4 days per week)
- Weekend trips back home for rural students every two weeks, an annual trip back home for international students, and a trip back home every 1 in 4 years for those living more than 5000 km away. Part-time students also have a weekly travel component

- Computer use: we consider both the embodied carbon and energy consumption associated with computer usage. Approximately 30% of students use laptops during lectures for presentation viewing, assuming 10 hours of lectures per week and an 80% participation rate in lectures as a best-case scenario
- Waste: removal and treatment of communal and selective waste on campus
- University water consumption

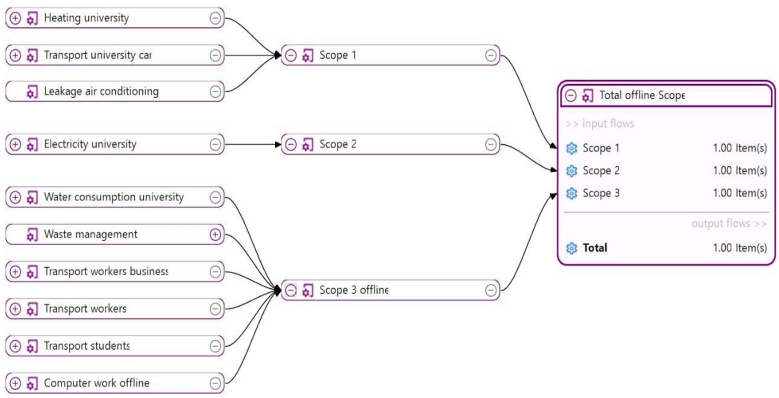


Figure 3

The model of in-person education in openLCA 2.0

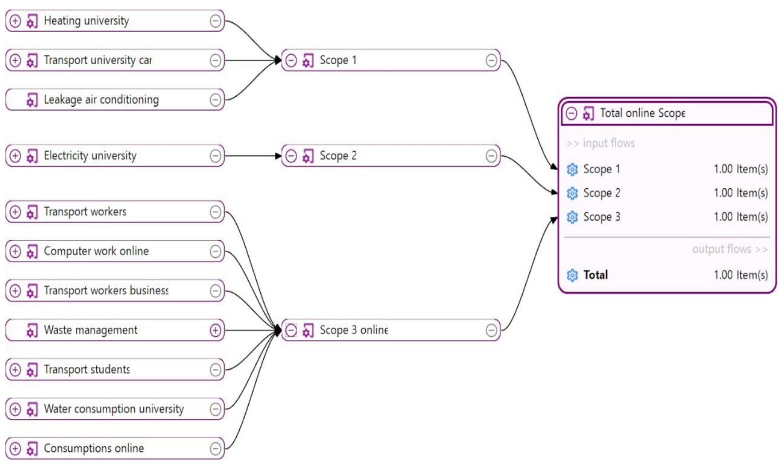


Figure 4

The model of hybrid education in openLCA 2.0

In the case of hybrid education (see also Figure 4):

We assumed lectures are online, while labs and exercises are in-person. Consequently, students need to attend the university for only two days a week physically, and they follow an average of 10 hours of lectures from home.

Scope 1 and 2 are unchanged, assuming operating buildings are still needed, so differences are only observed in Scope 3 emissions:

- Travel: changes compared to the entirely in-person mode: daily visits of students from Budapest and the agglomeration, reduced to 2 days/week, visits and travel of part-time students reduced to 8 consultations versus 14 per year
- Increased computer and internet use (both embodied carbon and energy consumption) due to "live" Teams lectures, downloadable videos and presentations being used at home
- Increase in the demand for home heating and lighting as students spend more time at home
- Waste quantity and water consumption unchanged

## 3.1 Data Collection

We gathered information on the energy and water consumption of the buildings, waste generation, and business trips from the technical staff of the Kandó Kálmán Faculty of Electrical Engineering and the university's financial director. The faculty head of education provided data on the number of students and their addresses (name of city or district in the case of Budapest), while other data were obtained from the university's website and curriculum tables.

To gain insights into students' transportation and eating habits, we conducted a questionnaire survey, although it had a relatively small sample size (28 responses). Using the survey results and statistics from the Budapest Transport Center [23], we extrapolated the transport choices for all students.

The survey responses regarding eating habits indicated no significant difference between having lunch at home and university. Few individuals opt for the university canteen, prefer fast food or street food, and many students bring lunch from home.

We relied in part on data from the Hungarian Central Statistical Office [24] to calculate the additional heating needs for homes during online education.

## 3.2 Results

The campus's total carbon footprint for 2022, when only in-person education was in place, amounted to 2223 tons of $CO_2$ equivalent. If we had introduced two days per week of online education, the carbon footprint could have been 12% lower, at

1957 tons, resulting in a saving of 266 tons. The key difference between these two scenarios mainly relates to scope 3 emissions. This finding is supported not only by our model but also by COVID-19 quarantine data. During the lockdown, gas consumption remained relatively stable, and there was only a modest 10-15% reduction in electricity consumption in the spring of 2021.

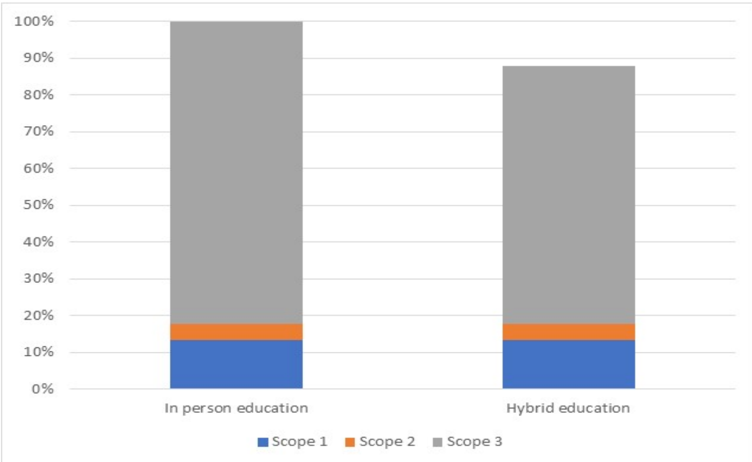


Figure 5
Comparing the carbon footprint of in-person and hybrid education

If we only consider the indirect emissions (Scope 3), the annual carbon footprint for in-person education is 1827 tons of $CO_2$ equivalent. The difference still stands at 266 tons.

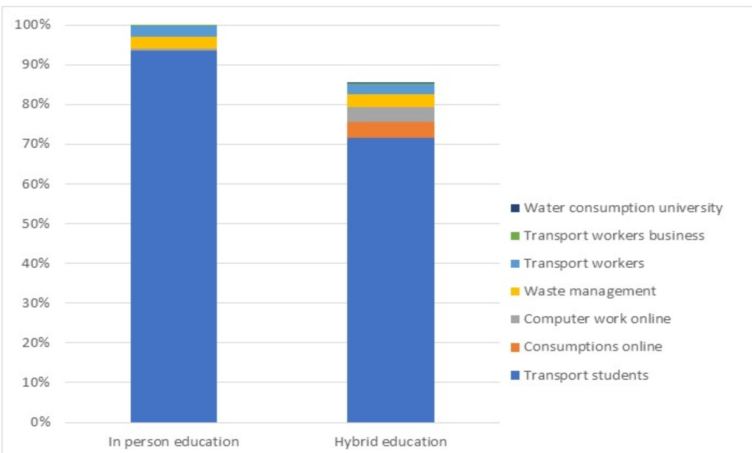


Figure 6
Share of Scope 3 emissions by different categories

To clarify further: "Consumption online" refers to the extra heating and lighting needed at students' homes during online education. "Computer work online" is related to the embodied carbon and energy used when students access the internet and use online educational materials.

Within the scope 3 emissions, the most significant factor is student travel. It's worth taking a closer look at this aspect (see Figure 7). Notably, the contribution of lecturers' business trips and university water consumption is negligible, making up less than 0.5% of the total emissions.

In the presentation of student travel, we have separated the daily commute and the weekend trip home for rural students. Despite similar education in other institutions in the country, the University attracts many students from rural areas. As such, overall output. Unfortunately, there is limited scope for change in this regard, which remains consistent with the online education model.

There are relatively few students who commute by car, but their contribution to the impact is significant. The 15% of all trips in km terms account for 42% of $CO_2$ emissions. In international comparison, student car use is relatively low, so no significant reduction is expected in this area. We didn't include pedestrians, cyclists, and scooter users in the diagram, as they don't generate emissions. In the in-person education model, these environmentally friendly modes of travel cover nearly 350,000 kilometers annually, constituting 5% of the total distance travelled. 85 foreign students attend the two faculties, and their travel home emissions barely exceed 1% of the total.

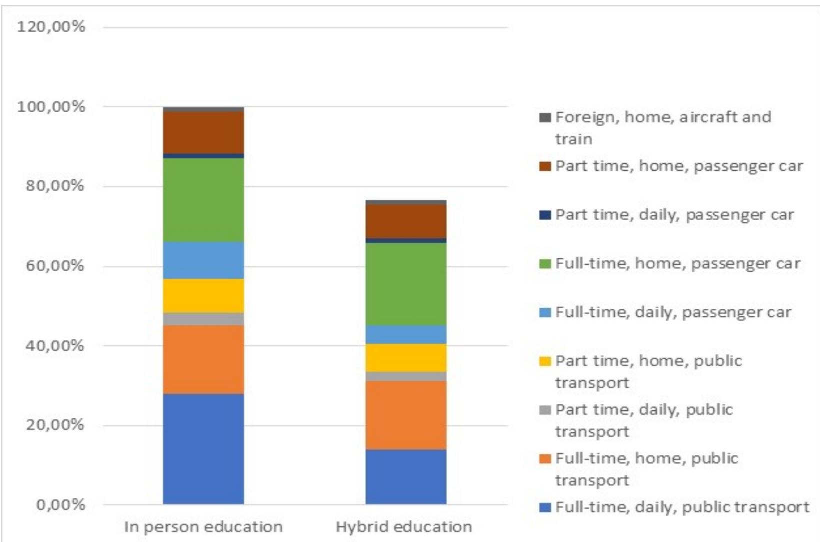


Figure 7
Share of travel emissions by type

In our analysis, we applied the data collection and calculations to the entire campus for one year, but to make it easier to compare the results, we used the emissions of a single student studying for one hour as a reference point. The table below shows the emissions data, calculated by the time spent indoors by the students during study and exam periods. The first two columns show the emissions of the entire campus; the second provides data for a typical day, while the third two offer data for each hour of study.

Table 1
Carbon footprint results for the case study

| | Campus total | | Daily emissions | | Hourly emissions | |
|---|---|---|---|---|---|---|
| | In-person | Hybrid | In-person | Hybrid | In-person | Hybrid |
| | kg $CO_2$ e | kg $CO_2$ e | kg $CO_2$e/ capita / day | kg $CO_2$e/ capita / day | kg $CO_2$e/ capita / hour | kg $CO_2$e/ capita / hour |
| **Scope 1** | 296775 | 296775 | 0,5586 | 0,5586 | 0,1540 | 0,1540 |
| **Scope 2** | 99019 | 99019 | 0,1864 | 0,1864 | 0,0514 | 0,0514 |
| **Scope 3** | 1827282 | 1560893 | 3,4392 | 2,9378 | 0,9481 | 0,8099 |
| ***of which travel*** | *1711234* | *1309250* | *3,2208* | *2,4642* | *0,8879* | *0,6793* |
| **Total** | **2223077** | **1956688** | **4,1841** | **3,6827** | **1,1534** | **1,0152** |

# 4 Discussion

The calculated carbon footprint data seems reasonable if compared to other relevant data in the literature (e.g., Genta et al., 2022) [12]. It's worth noting that our campus's carbon footprint is notably lower compared to similar studies conducted at other universities [13-15]. What's particularly striking is that while transportation contributes significantly to emissions in various cases, the proportion we calculated, exceeding 80%, is an outlier.

The primary explanation for this discrepancy is that, in our analysis, we included the relatively frequent trips home made by rural students and the daily visits by other students. It's important to note that we couldn't find conclusive evidence in the literature we reviewed, either in favor or against such inclusion.

When we compare our calculated 4.2 kg emissions with the national per capita emission, which stands at 18.4 kg per inhabitant per day (HCSO 2022) [24], the approximately 4x multiplier, appears to realistically reflect the difference.

## 4.1 Campus Decarbonization Opportunities

The proposed possible solutions have been classified into three groups: energy supply and savings, the decrease in emissions that can be achieved by organizing education, and solutions that support environmental education.

### 4.1.1 Energy Supply and Savings

Following the typical development and renovation approach, the first step would involve the energy-efficient upgrade of the buildings. Buildings A and B, which serve as the primary educational facilities and have existed for over a century, are not designated as protected monuments but possess attractive facades and sturdy main walls. External thermal insulation is not a viable option for these structures. Therefore, the viable solution is to replace the windows and refurbish the heating, ventilation, and air-conditioning (HVAC) system. This combined effort would yield significant environmental benefits, although the intricate technical and financial aspects fall outside the scope of this research. Building C stands out as the least energy-efficient, characterized by a disproportionately high demand for heating and cooling. Consequently, an additional thermal insulation layer can be applied to this building. On the other hand, Building G boasts a more contemporary design and an efficient HVAC system.


Figure 8
The campus on the solar map, with the peak power of installable solar panels (kWp) [25]

The following logical recommendation involves harnessing renewable energy sources, with solar and thermal collectors being the only viable options due to the campus's characteristics. According to the solar map of Budapest [25], the area offers moderately favorable conditions for solar energy generation. By fully utilizing the available surface area, it becomes feasible to install a small photovoltaic (PV) power plant with a capacity of nearly 400 kWp, generating approximately 400 MWh of energy annually.

This annual production significantly surpasses the campus's energy consumption. Figure 14 illustrates three years of monthly energy consumption data compared to the expected energy production of a 200 kWp solar power plant. These data demonstrate that the university could fulfil its electricity requirements through solar panels with some prudent energy use.

However, the extent to which we utilize this capacity remains uncertain, even when considering a switch to electric heating. This is complicated due to the regulations governing two-way energy exchange. This challenge arises because such an exchange may not be advantageous for an institution that temporarily shuts down during the summer when solar energy generation is the highest.

Of course, we cannot forget the embodied carbon content of the installed PV system in the environmental assessment. Based on the EPD data of several monocrystalline Si solar cells, we calculate this to be 34 kg $CO_2$/kWp/year [26].

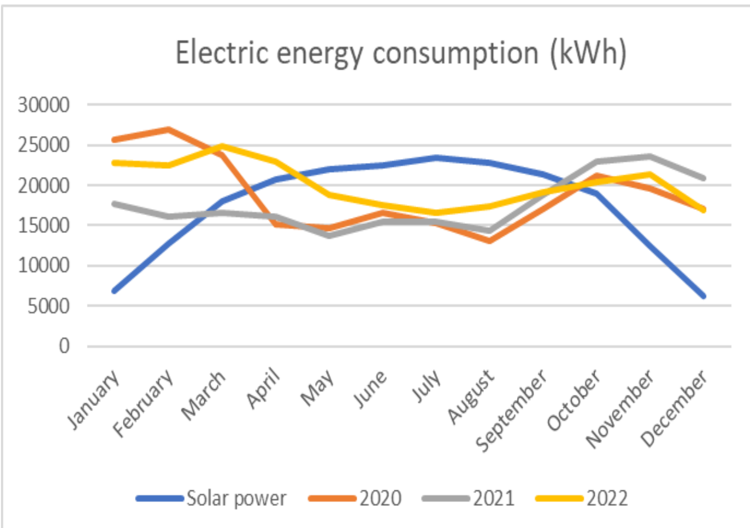


Figure 9

Total electricity consumption of the campus in kWh in the last 3 years and the energy output of a 200 kWp solar PV installation

### 4.1.2 Transport

The existing literature and our analysis indicate that daily commuting and traffic results in the most significant environmental impact. As such, adopting measures like implementing partial online education and remote work can yield substantial improvements, which we will elaborate on later. Furthermore, enhancing support for bicycle accessibility through the addition of more parking spaces, as well as offering amenities like changing rooms and showers, is essential. Similarly, promoting e-rollers and e-bikes can be achieved by ensuring safe storage and charging options. It's worth noting that other modes of transportation such as business travel of the staff to meetings and other events contribute negligibly to the overall environmental impact.

### 4.1.3 Environmental Education

To effectively enhance environmental awareness and promote a culture of sustainability on university campuses, it's crucial to implement a combination of strategies. For students and educators, practical examples and positive reinforcement play a significant role in strengthening environmental consciousness. Everyday practices like selective waste collection, reducing paper usage, and minimizing packaging waste are prime opportunities for involvement. This can include placing more recycling bins in campus corridors, transitioning to electronic educational materials and records, and engaging electrical engineering students in discussions about e-waste management and recycling despite the limitations of disposal rules and waste regulations.

Another closely related area for improvement is lighting. Many areas on campus still use fluorescent lighting, and there are no classrooms with adjustable lighting. Students specializing in lighting engineering could play a vital role in modernizing the lighting infrastructure.

Expanding students' environmental knowledge, especially concerning their chosen field of expertise, is paramount. This could be achieved through standalone environmental courses or by integrating environmental topics into specialized subjects.

## Conclusions and Recommendations

Our analysis assessed the environmental impact of university education as a whole, not just that of the institution. Consequently, if a portion of the education is delivered at the student's residence, the institution's environmental footprint may decrease. However, the overall environmental impact of education is determined by the difference in carbon emissions between university and home-based learning. Our analysis provides actionable insights for effectively reducing emissions. Regarding scope 1 and 2 emissions, we find ourselves reiterating well-established environmental protection practices, such as improving insulation, adopting renewable energy sources, and using energy-efficient lighting.

After reviewing the existing literature, it became evident that there isn't a standardized protocol for evaluating the carbon footprint of universities. Most studies, including ours, have relied on the organizational carbon footprint calculation requirements. [16-18]. Two approaches are commonly used when quantifying $CO_2$ emissions for individual components: emission factor tables and calculators available from various sources [19]. In our study, we opted for a Life Cycle Assessment (LCA)-based calculation, employing the extensively documented and comprehensive Ecoinvent database for greater accuracy.

The next question is the definition of the system boundary. Almost no analysis uses the same system boundary. This applies to the elements of the 3 scopes; the first two are mandatory. Since no product in education helps to focus between significant and avoidable processes, access to data and time usually determines what is included in the study, even if researchers generally strive to present the whole picture.

- In our analysis, stationery, paper use, building maintenance, and cleaning remained outside the system boundaries mainly due to lack of data and time.
- The assessment of food is controversial; according to many, it should not be linked to the university. There is a canteen on campus, but the students hardly use it, so we can safely say there is no difference between the lunches of the day spent at the university or elsewhere, so we omitted this.
- Special formulas should have been developed to calculate the embodied carbon content of the purchased devices. According to the general procedure, the amortization period of the acquired assets is 3 to 5 years. Due to the relatively poor financial situation of the university, the equipment park is much older than this, many 10-20-year-old instruments are used in the laboratories, and the computers are not replaced after 3 years. This can even be considered beneficial from an environmental point of view, but the instructors are not proud of it.

There is no clear agreement on the definition of the unit of reference, although this is the first condition for comparing two institutions. Normalization for one student is obvious; the choice can be based on the time base. Finally, we chose the emissions for a day and an hour as reference. We counted only the educational days (190 days/year) or educational hours (722 hours/year) instead of calendar days and hours.

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