Is Open, Distance, and Digital Education (ODDE) good for the environment?
A systematic review of carbon footprint studies

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Abstract
This study presents a systematic review of research on the environmental sustainability of Open, Distance, and Digital Education (ODDE), focusing on its carbon footprint. Although higher education institutions (HEIs) are expected to reduce greenhouse gas emissions, the environmental impacts of teaching and learning modes remain underexplored compared to campus operations. To address this gap, 17 studies published between 2002 and 2025 were examined. The evidence shows that ODDE typically generates far lower emissions than campus-based education, mainly through reduced travel and campus energy use and the benefits of centralized delivery. Landmark studies reported reductions of more than 80% compared to face-to-face teaching. Studies conducted during the COVID-19 pandemic confirmed significant savings but also highlighted rebound effects, as household energy use increased while campus facilities continued to consume resources. Emerging technologies, particularly generative AI, further complicate the picture due to their high energy demands. Overall, the evidence suggests that ODDE can contribute positively to reducing the carbon footprint of higher education. However, the small number of studies, lack of standardized methodologies for carbon footprint assessment (CFA), and limited attention to rebound effects constrain broader generalizability. Future research should systematically compare different delivery models across diverse institutional contexts and develop shared CFA guidelines. Strengthening the sustainability profile of ODDE is of critical importance, not only for the higher education sector but also for advancing global climate goals.

Keywords: Open, distance, and digital education; ODDE; Sustainability; Carbon footprint; Greenhouse gas emissions; Systematic review

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In the context of global warming and ongoing digitalization, scholars have increasingly questioned the environmental effects of educational technologies used in digital education and online learning (e.g., Macgilchrist, 2024; Selwyn, 2025). Generative AI applications are particularly resource-intensive, with considerable carbon footprints and other environmental effects. Bozkurt (2025), for example, reviewed their energy and water consumption and generation of electronic waste. This study focuses on the carbon footprint of online learning and its associated infrastructure, using the Sustainable Development Goals (SDGs) as a guiding framework.

The United Nations World Commission on Environment and Development, established in 1983, significantly shaped the contemporary understanding of sustainability. The commission's 1987 Brundtland Report, *Our Common Future*, provided a definition of sustainable development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987, para. 27).

The 1992 Rio Declaration, issued at the United Nations Conference on Environment and Development, is regarded as a key milestone in advancing sustainability. Its action plan, Agenda 21, addresses the economic, social, and environmental pillars of sustainable development. It calls on countries to establish monitoring and evaluation systems, using indicators to track changes across all three dimensions. Protecting the environment and its ecosystems is central to sustainability because environmental constraints place limits on economic and social development. In September 2015, countries from across all continents adopted Agenda 2030, comprising the 17 SDGs and 169 targets. These goals apply to nations as well as organizations, including higher education institutions (HEIs).

Elkington (1994) extended the concept of sustainability to organizations. Elkington's Triple Bottom Line Model of Sustainability considers the potential impact of managers' decisions on organizational profits, people, and the planet. The main argument is that organizational leaders have a threefold fiduciary duty: they must pursue profits for shareholders, act responsibly toward people affected by their business, and safeguard the environment impacted by their operations. Applied to higher education, the "products" are graduates prepared to become responsible and critical members of society; the "people" are students and other members of university communities; and the system, through its operations, affects the environment.

HEIs should assume a leading role as sustainable institutions in the fight against climate change. They can lead by example and influence the attitudes of individuals and future decision-makers in business, politics, and academia (Filimonau et al., 2021). Reducing the environmental effects of human activity will require insights from social and psychological research to develop environmentally sustainable ways of living, with education playing a central role in promoting them (Campbell & Campbell, 2011).

However, HEIs require extensive operations that generate substantial carbon emissions. In some countries, legislation now mandates universities to reduce these emissions as part of the net-zero agenda. For example, in the UK, the Higher Education Funding Council (HEFCE) set ambitious carbon reduction targets in line with the 2008 UK Climate Change Act, aiming to cut emissions by 83% by 2050 compared to 1990 baseline levels (see Caird et al., 2015).

Efforts have focused on reducing the energy use and emissions associated with campus operations, including travel, building operations, and energy sources (e.g., Patella et al., 2025; Versteijlen et al., 2017; Yin et al., 2022). However, these measures are only indirectly related to teaching and learning models. Although teaching is the core function of HEIs, few studies have examined the effects of different delivery modes. One exception is the SusTEACH methodology developed at the Open University UK (Caird et al., 2015; Carr et al., 2019).

This study focuses on different delivery formats and their associated carbon footprints and environmental effects. Teaching formats exist along a spectrum from face-to-face to fully online learning based on their degree of digitalization. We use the definition of Open, Distance, and Digital Education (ODDE) provided by Zawacki-Richter and Jung (2023):

> We conceptualize ODDE as an overarching term to refer to all kinds of learning and teaching processes in which knowledge and skill base of educational technology, digital media, and tools are used to present and deliver content, as well as facilitate and support communication, interaction, collaboration, assessment, and evaluation. Thus, ODDE is not monolithic in form. It includes various practices, from technology-enhanced education, to flipped learning and blended learning to fully online education. (p. 4)

Mark Nichols, president of the International Council of Open and Distance Education (ICDE), argues that ODDE is sustainable, "characterised by, one, a low carbon footprint and, two, long-term financial viability while providing a quality, reliable service" (Nichols, 2024, p. 228). The Green Campus Task Force report published by the European Association of Distance Teaching Universities (Ubachs et al., 2024) highlights green campus initiatives undertaken by European distance teaching universities:

> A "Green Campus" refers to a Higher Education Institution (HEI) campus that is designed, built, and operated in an environmentally sustainable manner. This can include a variety of initiatives such as energy efficiency, use of renewable energy sources, recycling and waste reduction programs, sustainable transportation options, and conservation of natural resources. Green campuses also often include green spaces, such as gardens and parks, which provide habitat for wild-life and opportunities for outdoor recreation for students, faculty, and staff. (p. 2)

This definition appears to be broadly applicable to any university, perhaps even more so to a campus-based institution. Although it strongly emphasizes environmental sustainability, it does not address the distinctive characteristics of ODDE or its positive and negative environmental effects. Regarding sustainability in HEIs, Lane (2025) notes that "the key to success is for a university or college to define sustainability for itself and build a unique strategy and structure which reflects its nature, context, and geography" (p. 8).

Asha Kanwar, former President of the Commonwealth of Learning (COL), emphasizes the need for more research in this area: "[…] distance education can reduce costs, improve quality, and increase access and equity. But now we've got another dimension, the ecology dimension where we need more of research" (Johnson & Cefa, 2024, p. 7).

In their systematic review of carbon footprint assessment methods in HEIs, Valls-Val and Bovea (2021) note that no standardized methodology exists for assessing the carbon footprint of educational institutions. They emphasize that "no specific reviews have been done for educational activities" (p. 2525), that is, teaching operations.

Against this background, this systematic review addresses the following research questions:

- RQ1 Publication and authorship patterns: How has the number of studies on the environmental impact and carbon footprint of ODDE developed over time, in which journals and other publication outlets are they published, who are the leading authors and what is their country of origin?
- RQ2 Carbon footprint assessment (CFA): What methods and factors are used to measure the carbon footprint of ODDE, and which type of HEIs are involved? What results are reported regarding the carbon footprint of ODDE, and in comparison, to on-campus face-to-face teaching and learning?

Put simply, we want to examine whether ODDE is good for the environment and what it can contribute to combating climate change.

Before outlining the methodology of our systematic review and presenting our results, we will first provide a brief overview of already published systematic reviews on the general topic of sustainability and environmental impacts in higher education and explain how our review differs from them.

Previous Reviews on Sustainability and the Environmental Impact of Higher Education

To start with, some reviews focus broadly on the impact of higher education on the SDGs and sustainable development. The first is Findler et al. (2019), who developed a sustainable development impact framework of HE institutions, highlighting direct and indirect impacts (e.g. greenhouse gas emissions caused by operations and contribution to climate change) based on 113 articles published between 2005 and 2017. They highlight the need to analyse existing sustainability assessment tools in HE regarding their ability to effectively examine the impacts of HEIs on sustainable development.

In this regard, Basheer et al. (2024) explored sustainability assessment practices in HE by means of a content and bibliometric analysis of 83 articles from 2018 to 2023. They provide a comprehensive overview of holistic sustainability assessments (e.g. studies on frameworks and tools, sustainability indicators) and also focus on the environmental dimension with studies on green campus initiatives, environmental sustainability, and carbon footprint assessment, and sustainable mobility. However, an assessment of the teaching operations plays no or only a very minor role here.

Qiu and Dong (2024) explore the existing research on environmental impacts generated from the entire life cycle stages of campuses based on 135 articles published between 2003 and 2023. According to the Greenhouse Gas (GHG) Protocol, three scopes of direct and indirect GHG emissions are distinguished: Scope 1 direct emissions (e.g. on-campus use of natural gas for heating and cooling), Scope 2 indirect emissions (e.g. purchased electricity), and Scope 3 other indirect emissions (e.g. student and staff transportation). Qiu and Dong (2024) found that the majority of studies focused on Scope 1 and Scope 2 emissions, with only eight articles analysing Scope 3 emissions. They therefore suggest incorporating Scope 3 emissions into the life cycle analysis of carbon assessments.

Umar et al. (2024) carried out a bibliometric mapping review of publication trends in sustainability and HE. Their corpus included 262 articles over a one-year period. Most articles were coming from European countries and the USA, but only few from Asian countries. The journal with the highest number of publications was the *Journal of Sustainability*, followed by the *International Journal of Sustainability in Higher Education*, and the *Journal of Cleaner Production*. They note that the sustainability performance assessment has gained momentum in the post-COVID-19 period.

There are three other systematic reviews from 2020, 2023, and 2024 that have specifically addressed the carbon footprint of HEIs. The review by Valls-Val and Bovea (2021) has already been mentioned; it is based on 35 papers and primarily calls for a specific methodology with standardized factors for the carbon footprint assessment of HEIs. Like Qiu and Dong (2024) they also found that many institutions have accounted for just Scope 1 and 2 in their carbon footprint reports because they are the easiest and cheapest to assign and calculate. They note that quantifying Scope 3, other indirect emissions, can be quite challenging for HEIs.

Another bibliometric analysis on research trends of universities' carbon footprint was carried out by Ma et al. (2023). They note that an accurate assessment of carbon footprint is one of the key elements to evaluate progress towards sustainable development. The bibliometric dataset contained 273 publications between 2009 and 2022. Based on a content analysis, they conclude that future research should focus on analytical frameworks, sustainable commuting, eco-recycling, green curriculum, energy consumption behavior, and energy conservation.

The most recent systematic review was published by Paredes-Canencio et al. (2024) based on 50 articles and reports up to 2022. They confirm the finding of previous reviews that the majority of studies focus on Scope 1 and 2 emissions. The most evaluated emission sources were the consumption of electrical energy (78%), transportation (74%), and the use of fuels (64%). They also call for a specific carbon footprint guideline for universities that would improve the carbon footprint assessment and would allow better comparisons between HEIs.

Based on the current literature we can conclude that, on the one hand, there are systematic reviews that take a very general and broad approach to the topic of university sustainability, considering not only environmental but also social and economic dimensions. On the other hand, there are several systematic reviews that focus specifically on the carbon footprint of universities, though their emphasis lies on campus operations rather than on the actual teaching and learning processes, and the teaching modes of delivery, and the associated direct and indirect environmental impacts. Our aim with this systematic review is to help close this gap, and in the following, we describe our methodological approach.

Method

A systematic review seeks to address well-defined research questions through a transparent and replicable search strategy, applying explicit inclusion and exclusion criteria to determine eligible studies (Gough et al., 2017; Zawacki-Richter et al., 2020). Data from the included studies are subsequently coded and extracted to synthesize findings and identify gaps or inconsistencies. Following established methodological guidance (Newman & Gough, 2020), the process involves formulating the review question and protocol, defining eligibility criteria, designing the search strategy and identifying information sources, screening studies against the criteria, presenting search results in a flowchart, extracting descriptive data, appraising study quality, and synthesizing the evidence. This structured approach enhances both transparency and reproducibility.

The protocol for this review (including a RIS-file containing bibliographic information for all 17 articles) was registered and published on the Open Science Framework (OSF) platform (https://osf.io/) and is available via the following link: https://osf.io/jcrup/.

Search Strategy and Data Retrieval

The authors formulated a broad search string (see Table 1) for this systematic review to retrieve relevant studies. The articles were retrieved from four international databases: Education Source, Scopus, Web of Science, and IEEE Xplore. By selecting these databases, we were able to ensure that both studies from the field of education and more technically oriented work were captured. In particular, the IEEE Xplore database provided numerous results from conference proceedings in the engineering sciences.

Table 1

Search String

Topic	Search string
Study focus	(carbon OR ecological OR sustainab* OR “greenhouse gas”) NEAR/3 (emission OR report* OR assess* OR footprint OR impact)
	AND
Education level	("higher educat*" OR universit* OR college OR post-secondary)
	AND
ODDE	(digital OR distance OR online OR mobile OR open) NEAR/3 (edu* OR program* OR teach* OR learn*)

The inclusion and exclusion criteria (see Table 2) for this systematic review specified four key dimensions for inclusion and exclusion: publication year, publication language, education level and setting, and the document type. No time limit was set to include studies from all available years, provided the studies addressed higher education involving ODDE interventions.

To maximize the retrieval of studies that might include carbon emission calculations, the review included journal articles, conference proceedings, and book chapters. Short reports, editorials, commentaries, and letters were excluded, as were any studies that explicitly fell under the review methodology category (i.e. systematic reviews, scoping reviews, or other literature reviews).

Table 2

Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Time	no limit	-
Language	English	not in English
Education level	higher education	early childhood education, K-12, non-formal, informal education
Education setting	open, distance, and digital education (ODDE)	not related to ODDE
Intervention	carbon emission calculations involving ODDE	carbon emissions in conventional campus settings only; studies focusing on learning about sustainability; classes aiming to foster environmental sustainability through engineering or architecture; awareness-raising interventions for environmental sustainability
Scope	environmental sustainability	other sustainability domains (e.g., social, economic)
Document type	journal articles, conference proceedings, book chapters	reports, editorials, commentaries, letters

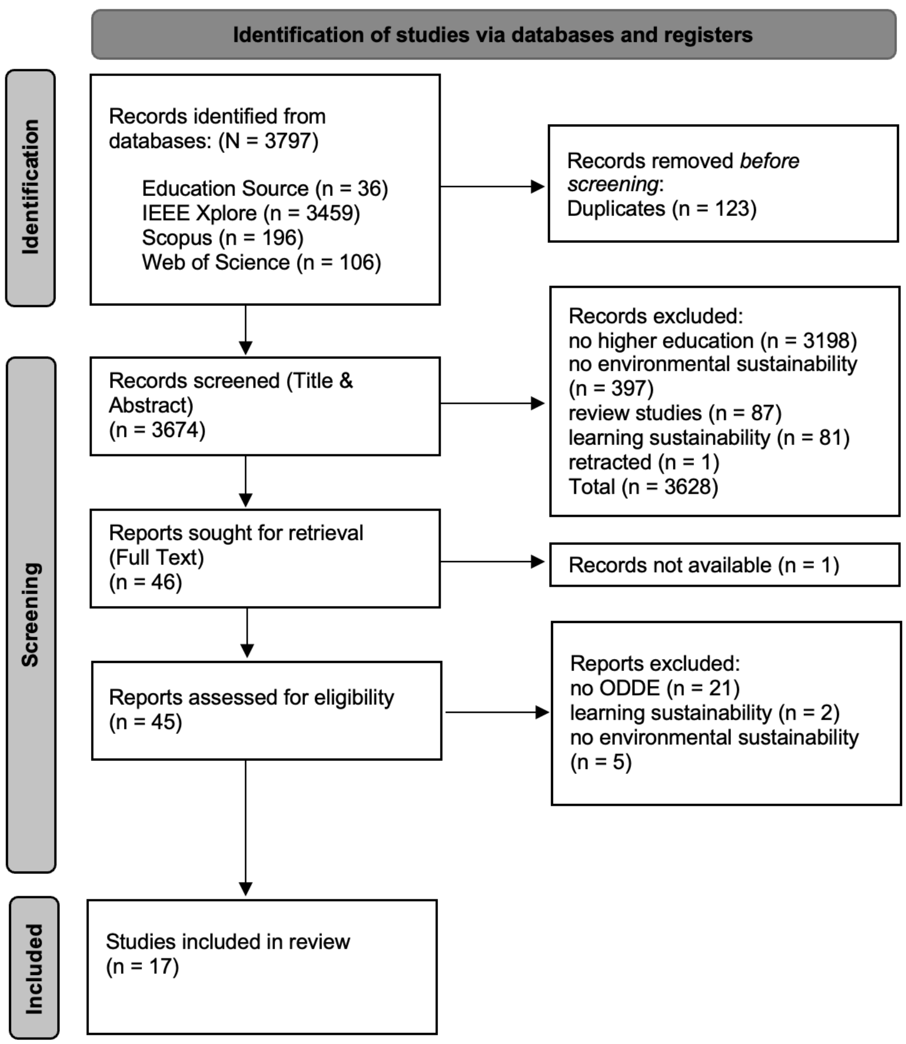
Screening and Coding Process

After alignment discussions among three coders on the duplicate-clean data set (N = 3,674), a blind Abstract and Title Screening (A&T) review was conducted on a randomly selected sample of 100 studies. After the initial screening, the Fleiss' κ agreement was κ = 0.50, which was lower than expected due to differing interpretations of "environmental sustainability." Following a reconciliation meeting, a second round of screening was conducted on a new sample, resulting in only one inclusion decision. Although there was full agreement on this second sample, the authors opted to repeat the process using a purposefully selected sample from the corpus. This was because the IEEE Xplore database returned many articles unrelated to higher education alongside relevant ones.

For the third round, 100 studies most relevant to higher education were sampled, and coders achieved perfect agreement (κ = 1.00). The proportion of inclusion and exclusion decisions became more balanced compared to earlier rounds, though exclusions still predominated. The authors recognized that κ – whether Cohen's κ for two raters (Cohen, 1960) or Fleiss' κ for multiple raters (Fleiss, 1971) – measures agreement beyond chance by comparing observed agreement to expected agreement based on marginal category proportions. This adjustment can sometimes produce the "asymmetry problem" (also called the prevalence paradox), in which κ is low despite high raw agreement if one category (e.g., "exclude") is chosen far more often (Byrt et al., 1993; Randolph, 2005).

Figure 1

PRISMA Flow Diagram, slightly modified Moher et al. (2009)



To minimize the influence of chance agreement, the authors conducted a fourth and final round of screening. This round again yielded perfect agreement among the three raters, with κ = 1.00 and a 100% raw agreement rate. Since the observed and expected agreements were identical in the sense of no prevalence imbalance, there was no paradoxical situation in this final test, and the authors retained the final κ calculation as representative of the subsequent A&T screening, which the authors conducted individually.

After A&T screening, the tentative coding scheme was finalized, and full texts were retrieved. Following a Cohen's κ calculation (κ = 1.00) confirming perfect agreement on the finalized scheme, coding proceeded individually by the authors. Despite the rarity of achieving such agreement, the coders concluded this was due to the specificity of the review questions. The coding scheme included categories capturing the corpus characteristics (e.g., publication year, journal, country), the carbon emission calculation approaches employed, the factors included in these calculations (such as energy consumption, transportation, material use), and the data sources from which calculation inputs were drawn. This structured approach ensured that coding decisions were consistently anchored in the agreed-upon definitions and categories, maintaining reliability throughout the full-text analysis and subsequent synthesis.

The software tool Rayyan was used to support the entire screening process, while data extraction for the 17 included studies was conducted using an Excel spreadsheet.

Limitations

To the best of our knowledge, this study covers all relevant studies within our research scope in this area. However, as with any research, this study is subject to certain limitations. The first limitation concerns language. If relevant studies were published in local databases in the home-country language, they could not be retrieved, as the search was conducted in English. The second limitation is the database scope: the review was restricted to four databases, one of which is particularly strong in engineering and natural sciences and provided a substantial yield, but others may contain relevant studies that were not captured. A related constraint involves document type in relation to publication language. Although dissertations and theses were not intentionally excluded, some relevant works may remain in local repositories in non-English languages and thus were not indexed in the selected databases.

Finally, the inclusion criteria themselves also limited the scope: the study aimed to identify what ODDE might contribute to CO_2 emission policies, so carbon emission studies based solely on conventional education, without reference to off-site practices, were excluded. While these were outside the review's scope, they could still offer useful insights into theoretical frameworks and calculation approaches applicable to fully on-site systems.

Results and Discussion

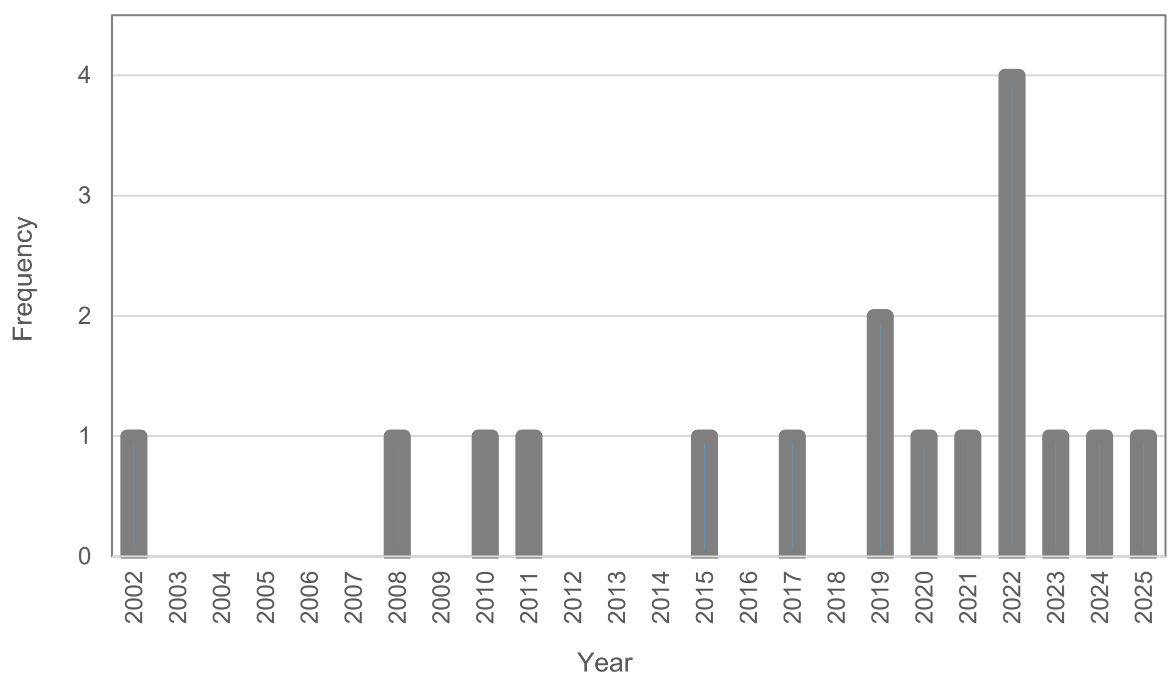
RQ1: Publication and Authorship Patterns

<u>Publications per Year</u>

Figure 2 shows the number of papers per year from 2002 to 2025. The distribution indicates that the topic of environmental sustainability related to ODDE has been scarcely addressed in the literature. Until 2018, only a few articles on the topic were published. It was only from 2019 onwards that articles began to appear annually, with the peak occurring in 2022 at four publications. The relative concentration of publications in 2022 suggests that these studies were conducted during the COVID-19 pandemic and likely focused on examining the effects of lockdowns and emergency remote teaching on the carbon footprint of universities.

Figure 2

Number of Included Articles per Year (N = 17)



<u>Publication Types</u>

The majority of the studies (n = 15) were published in academic journals. Two articles were published in the *International Journal of Sustainability in Higher Education*, other journals included the *Environmental Impact Assessment Review*, the *Online Journal of Distance Learning Administration*, *Current Opinion in Environmental Sustainability*, *Sustainability (Switzerland)*, and *Environmental Research: Infrastructure and Sustainability.* One study was published as a book chapter and one in the *IOP Conference Series: Earth and Environmental Science*.

Countries

For the analysis of the country-wise distribution of articles, the first author's country was considered (*n* = 12 countries). Most studies originated in Great Britain (*n* = 5) and the United States (*n* = 2). The following countries each contributed one study: Australia, China, Indonesia, Italy, the Netherlands, the Philippines, South Africa, Spain, Thailand, and Turkey.

Leading Authors

The authors who published the most studies on this topic were all affiliated with the same research institution in the United Kingdom: the Department of Engineering and Innovation at the Open University. They published together until 2015. Four authors were each involved in three publications, including Sally Caird, Andy Lane, Robin Roy, and Ed Swithenby. Stephen Potter contributed to two articles.

RQ2: Carbon Footprint Assessment (CFA) in Relation to ODDE

All studies included here examine the carbon footprint of HEIs with regard to institutional organization or the provision of courses and programs in ODDE formats. Table 3 provides an overview of the study settings, thematic scopes, methodological approaches, and results. Studies from open and distance teaching universities are particularly well represented, including the Open University UK (GB), the Open Universiteit (NL), and the University of South Africa (ZA). Of the 17 studies, 14 conducted their own carbon footprint assessment (CFA) to compare different delivery formats or the impact of specific teaching operations; these will be discussed in detail below.

The following three studies (Versteijlen et al., 2017; Jarillo et al., 2019; Louw, 2022) did not conduct their own CFAs or calculate emissions but instead discussed various aspects of the carbon footprint of higher education in relation to ODDE.

Versteijlen et al. (2017) from the Open University of the Netherlands discuss the advantages and disadvantages of online education as a measure to reduce the carbon emissions of HEIs in the Netherlands. They draw on the classification of greenhouse gas emission sources according to the GHG Protocol (WBCSD/WRI, 2015) and analyze GHG reports from various Dutch universities. Their results focus on Scope 3 emissions (student and staff commuting and travel). Based on the literature review, they conclude that online education could make a significant contribution to reducing the carbon footprint: "Another strategy to reduce student travel emissions is the use of online education, and this seems to have great potential" (p. 82). Against this background, the authors discuss the advantages and disadvantages of online learning based on qualitative expert interviews. The emphasis, however, is not on the environmental impacts of online learning, but rather on pedagogical aspects, including the interaction between students and instructors, among students themselves, and between students and the presented learning materials.

In a conceptual paper, Jarillo et al. (2019) discuss the challenges and opportunities of online higher education in relation to SDG 4 (quality education), SDG 10 (reduced inequalities), and SDG 13 (climate action). The article therefore also addresses broader issues of equitable access to high-quality education through flexible online education. With regard to SDG 13, the authors consider the carbon footprint of an HEI in a case study of an online university with approximately 42,000 students. However, the analysis relies solely on emission measures reported in the literature, which are applied to the case. This approach yields only a rough estimate of the potential CO_2 savings achievable through online delivery.

Louw (2022) used a case study and employee survey at a very large distance teaching university in South Africa to investigate staff commuting patterns (Scope 3 emissions) and discuss the findings in relation to policies intended to promote telecommuting (i.e., working from home) and thereby reduce traffic-related emissions. The reported level of telecommuting was very low: 81.5% of respondents reported commuting to campus five days a week, and, of greater concern, more than 80% indicated that they did not carpool but instead drove alone.

Two Phases of CFA

The 14 studies that conducted and calculated a CFA can be divided into two phases over time. The first phase, covering the years 2002 to 2019, includes six studies that examined the carbon footprint of different delivery modes or calculated emissions from specific factors, such as printing study materials or student commuting behavior. The second phase was driven by the COVID-19 pandemic starting in 2020, during which reduced CO_2 emissions resulting from lockdowns and emergency remote online teaching were compared with pre-pandemic campus operations. This phase comprises seven studies, all conducted at conventional campus-based universities. In addition, one further article analyzes emission savings from online examinations at a distance teaching institution during the pandemic.

Phase 1 –Carbon Savings from Distance and Online Learning (2002–2019)

The first phase is dominated by a group of scholars at the Open University UK (OUUK), who, in two successive projects (the Factor 10 Vision Project and the SusTEACH Project), developed and applied the SusTEACH methodology to conduct an environmental assessment of courses using digital technology, face-to-face, and print-based teaching methods. UK legislation mandates universities to reduce carbon emissions as part of the net-zero agenda. In line with the 2008 UK Climate Change Act, the Higher Education Funding Council (HEFCE) set targets to reduce carbon emissions by 83% by 2050 compared with 1990 baseline levels.

Herring and Roy (2002) report on the Factor 10 Vision Project in which the environmental impacts of three different modes of UK higher education were compared: two conventional campus-based courses, a conventional print-based distance education course, and an electronically delivered distance education course. Energy consumption and CO_2 emissions were used as proxies for key environmental impacts. For comparability, all results were normalized per student per 10 CATS points, based on the UK Credit Accumulation and Transfer Scheme (1 CATS ≈ 10 study hours; 360 CATS for an undergraduate degree). The study revealed that OU conventional print-based courses used nearly 90% (factor of 10) less total energy and CO_2 emissions per student per 10 CATS points compared to the conventional campus-based courses, largely due to the elimination of commuting and reduced campus site energy consumption. The latter benefits from economies of scale in teaching thousands of students from a single central campus. Furthermore, e-learning, as implemented by the OUUK at that time, did not appear to lower total energy use and CO_2 emissions compared to print-based distance learning; in fact, the electronically delivered and tutored course required over 25% more energy and emissions per student per 10 CATS points.

A similar study employing the same methodology was conducted by Roy et al. (2008) with an expanded sample of 20 courses: 10 full-time and 3 part-time face-to-face campus courses, 3 part-time print-based courses, and 4 part-time online courses. The earlier findings were confirmed: Distance learning courses use 87% less energy and produce 85% fewer CO_2 emissions than full-time campus-based courses. Part-time campus courses achieved reductions of 65% in energy use and 61% in emissions compared with full-time campus courses. These lower impacts are largely attributable to reduced student travel, the elimination of much of the energy consumption associated with student housing, and more efficient campus site utilization. E-learning offers only modest additional reductions–20% in energy use and 12% in emissions–over primarily print-based distance learning, largely due to the higher energy demands of computing and increased paper use for printing.

Building on this previous work, the SusTEACH project further developed the methodology and applied it to 30 courses and modules from 15 different HEIs in the UK (Caird et al., 2015). The sample also included the 20 courses from the Factor 10 Vision Project, which were reanalyzed using the enhanced methodology. The study distinguishes between five different teaching models: the face-to-face teaching model, the distance teaching model, the online teaching model, and the ICT-enhanced distance teaching model and ICT-enhanced face-to-face teaching model. Energy consumption and CO_2 emissions were calculated for travel, ICTs, paper, print and other materials, residential energy, and campus-site operations.

The study found that distance education teaching models (paper-based, ICT-enhanced, and online) used on average 88% less energy and produced 83% fewer carbon emissions than campus-based models (face-to-face and ICT-enhanced face-to-face). The lowest impacts were recorded for online teaching, with 363 MJ of energy use and 36 kg CO_2 per 10 CATS points, representing reductions of 27% (online) and 21% (ICT-enhanced distance) compared with print-based distance teaching, largely due to lower material use and transport needs. In campus systems, ICT enhancement reduced carbon emissions by only 11% and had little effect on energy consumption, as ICT mostly supplemented rather than replaced in-person teaching. Overall, travel emissions accounted for the largest share of the emissions from the 30 courses examined (approximately 40%), although there were substantial differences between the various teaching models.

Finally, the SusTEACH method was also applied in a comparative study in Botswana (Carr et al., 2019). They compared a Bachelor of Business Administration program at the Botswana Open University (in which course content was distributed via CDs) with a program at the Botswana Accountancy College, a residential institution, and found that, on average, the carbon footprint of the face-to-face mode was nearly three times greater than the distance modality.

Table 3

Overview of Included Studies by Year (N = 17), Phase 1

Author(s)	Year	Ctry[1]	HEI type[2]	Measurement and Scope	Results
Herring & Roy	2002	GB	ODL	Comparison of print-based distance education vs. e-learning vs. f2f campus-based education; Scope: ICT energy, electricity, course-related travel, computer purchase and use, paper consumption, residential heating	Print-based distance vs. face-to-face campus: 90% less energy, 90% fewer CO_2 emissions; e-learning vs. print-based distance: 25% more energy, 25% more CO_2 emissions
Roy et al.	2008	GB	ODL	See Herring & Roy with an extended sample, including part-time courses	Distance learning vs. full-time campus: 87% less energy, 85% fewer CO_2 emissions; part-time campus vs. full-time campus: 65% less energy, 61% fewer CO_2 emissions; online vs. print-based distance: 20% less energy, 12% fewer CO_2 emissions
May et al.	2010	US	on-campus	Online courses; Scope: Student printing behaviour	47.05 t less CO_2 emissions over one year
Campbell et al.	2011	US	on-campus	Online courses; Scope: Student commuting	Ranging between 0.7 and 9.5 t less CO_2 emissions per course over the semester
Caird et al.	2015	GB	ODL	Comparison of print-based distance education vs. online learning vs. f2f campus-based education, including ICT-enhanced modes of distance and online learning; SusTEACH method; Scope: travel, purchase and use of ICT devices, books and publications, use of paper, home energy use, campus site operations	Distance education (paper-based, ICT-enhanced, online) vs. campus-based: 88% less energy, 83% fewer CO_2 emissions; online vs. print-based distance: 27% less energy, 27% fewer CO_2 emissions; ICT-enhanced distance vs. print-based distance: 21% less CO_2 emissions; total travel emissions share: ~40%
Versteijlen et al.	2017	NL	ODL	No CFA, review of Scope 3 emissions of Dutch HEI	Pros and cons of online learning
Carr et al.	2019	GB	ODL	Comparison of online learning vs. f2f campus-based education; see SusTEACH method (Caird et al., 2015)	Campus-based vs. online: three times higher CO_2 emissions
Jarillo et al.	2019	ES	ODL	No CFA, review HEIs impact on SDG 4, 10 and 13, and carbon footprint in HEI, case study on Int. University of La Rioja (41,870 students)	Estimates of CO_2 emission savings based on the literature

Table 3 (continued)

Overview of Included Studies by Year (N = 17), Phase 2

Filimonau et al.	2021	GB	on-campus	Comparison during COVID-19 pandemic, 2018-2019 vs. 2020, institutional data and interviews, Scopes 1-3	29% fewer CO_2 emissions in 2020; 45% electricity savings on campus; 51% gas consumption savings on campus; 73% share of emissions from learning and working from home
Salamena et al.	2021	ID	on-campus	Comparison COVID-19 pandemic, 2019 vs. 2020, Indonesia and Japan, institutional data and surveys, transportation and electricity consumption, Scopes 2 and 3	Emissions in 2019 (Indonesia: 549 t CO_2/; Japan 752 t CO_2), online learning emissions in 2020 (Indonesia: 10 t CO_2/; Japan 8.9 tCO_2); 96% transportation share
Yin et al.	2022	CN	on-campus	Comparison COVID-19 pandemic, 2011-19 vs. 2020, eight Chinese universities, institutional data, transportation and electricity consumption, Scopes 2 and 3	732 kt fewer CO_2 emissions from electricity consump-tion; 504 kt fewer CO_2 emissions from reduced transportation
Cortes et al.	2022	PH	on-campus	Comparison COVID-19 pandemic, 2019 vs. 2020, own GHG Inventory, University of the Philippines, Scopes 1-3	60.9% fewer CO_2 emissions in 2020
Heller et al.	2022	AU	on-campus	Comparison of f2f campus-based education vs. online; cohort of 128 international students; Scope 3: air travel, International Civil Aviation Organization (ICAO) carbon emissions calculator	969 t CO_2 emissions savings
Louw	2022	ZA	ODL	No CFA, review of Scope 3 emissions, survey, commuting of staff at the University of South Africa vs. home office (telecommuting)	Almost complete lack of telecommuting, >80% of vehicles carry only one person
Gümrükçüoğlu et al.	2023	TR	on-campus	Comparison COVID-19 pandemic, 2019 vs. 2020, institutional data, Scopes 1-3, emissions resulting from homework and study not included	47% fewer CO_2 emissions in 2020, mainly due to electricity savings
Prasara-A et al.	2024	TH	on-campus	Comparison COVID-19 pandemic, 2015-19 vs. 2020-21, TGO (2018) guidelines, Scopes 1-3	Annual per capita emissions (2015-2019: 0.35–0.37 t CO_2e; 2020-2021: 0.29 t CO_2e), electricity share (39-41%); 17-22% reduction; Scope 3 normal years (83–97 t CO_2e), 2020 (35 t CO_2e), 2021 (17 t CO_2e)
Patella et al.	2025	IT	ODL	Comparison COVID-19 pandemic, focus on impact of online exams, Scope 3, transportation	9,000 tCO_2e potential savings

Note.[1] International country code according to ISO 3166-1 alpha2; [2] ODL = Open and distance learning; on-campus = residential, campus-based learning

In the period 2002-2019, two further studies from authors from campus-based HEIs in the United States are available. Also referring to Elkington's Triple Bottom Line Model of Sustainability, May et al. (2010) examined the environmental impacts of online learning at the University of Dallas, focusing on a specific aspect: the printing behaviors of online students, based on 92 online course sections offered in an MBA program. Students were asked to estimate the proportion of downloadable documents and other printable materials they would normally print during an online class. To measure the environmental impact of printing, they used the Hewlett-Packard (HP) Carbon Footprint Calculator, which was designed to assess organizational printing activities. The students' responses were used to estimate the proportion of pages that would not be printed during each term. The authors conclude that the environmental benefits included saving 65,487 kW of energy, preventing the emission of 47.05 tons of CO_2, which is the equivalent of about 10 round-trip flights between New York and Los Angeles.

Campbell and Campbell (2011) also looked at a specific source of CO_2 emissions from online courses offered by three HEIs in California. To calculate emission savings from online courses, 500 students were asked in a survey about their usual mode of transportation to campus, miles per gallon used (if they drove), and their distance from campus. Total miles not driven were used to calculate savings in CO_2 emissions. Based on the commuting behaviour, the total mitigation of CO_2 ranged between 0.7 and 9.5 tons over the semester.

Phase 2 – COVID-19 Lockdown Impact Comparisons (2020–2025)

The second phase is characterized by articles examining changes in energy consumption and CO_2 emissions resulting from the lockdowns and the sudden shift to emergency remote online teaching during the COVID-19 pandemic. Six studies were published in this period, all conducted at traditional campus-based universities. In contrast to the first phase, where studies examined the impact of different teaching models or specific aspects of online education, the second-phase studies conduct carbon footprint assessments of entire higher education institutions, applying organizational boundaries in accordance with Scopes 1, 2, and 3 of the GHG Protocol.

The first study was conducted by Filimonau et al. (2021). It compares the carbon footprint of 2018 and 2019 with that of the first year of the pandemic in 2020 at Bournemouth University in the UK. The analysis draws on institutional data and interviews with students and staff to capture home-working conditions. Emissions were calculated using an input–output model, in accordance with the UK Government's guidance on corporate GHG reporting, covering Scopes 1, 2, and 3 emissions. During the lockdown, the carbon footprint decreased by about 29%, with the largest share of emissions (73%) arising from learning and working from home. Savings on campus were smaller than expected (45% in electricity use and 51% in gas consumption), indicating that even when the campus is not used, substantial energy is still required to maintain its operations.

The authors point to a significant rebound effect: Since working or studying from home can produce a carbon footprint comparable to commuting to the university, much of the carbon savings gained from moving education online to reduce student and staff travel can be largely offset. Referring to the SusTEACH studies and Versteijlen et al. (2017) in Phase 1, the authors note that online learning is not as environmentally friendly as suggested here. However, it should be noted that distance teaching universities serve large student populations from a small, centralized campus and are not directly comparable to large campus-based universities.

Salamena et al. (2021) compared the differences in CO_2 emissions between 2019 and 2020 for students in Japan and Indonesia. However, the study only considered electricity consumption and transportation.

In Indonesia, face-to-face learning resulted in at least 549 t CO_2 emissions per academic year, while in Japan, emissions reached 752 t CO_2 per year. In both countries, transportation was the largest contributor, accounting for approximately 96% of total emissions. During online learning, Indonesian students produced around 10 t CO_2 per year, and Japanese students emitted 8.9 t CO_2 per year, representing a substantial reduction compared with traditional in-person education. However, unlike Filimonau et al. (2021), the authors did not account for the fact that campus operations continue to consume substantial energy even when the facilities are not used. Therefore, the reported effects are likely to be significantly smaller.

Yin et al. (2022) focused on two sources of emissions—transportation and electricity consumption—and compared usage over the period from 2011-2019 with that of 2020 at eight Chinese universities. The study uses central institutional data and follows the *Guidelines on Enterprise Greenhouse Gas Emissions Accounting and Reporting-Power Generation Facilities*, issued by China's Ministry of Ecology and Environment. The authors conclude that the shift to online learning during the pandemic resulted in an unexpectedly large reduction in CO_2 emissions. The carbon emissions avoided through online Education amounted to 732 kt CO_2 from reduced electricity, and 504 kt CO_2 from reduced transportation.

At the University of the Philippines (UP), Cortes et al. (2022) compared the carbon footprint of 2019 with that of 2020, using a GHG inventory developed by the authors in 2018. In 2020, total CO_2 emissions were estimated at 555.8 t CO_2e, representing a 60.9% reduction compared with 2019. Per capita emissions in UP were 0.9 t CO_2e in 2019 and 0.3 t CO_2e in 2020, both remaining below the national average. The pandemic led to substantial emission reductions across most activities, except for fuel-related emissions, which rose by 305.8%. The increase in Scope 3 fuel consumption was due to the decision of the university to provide a shuttle service between two campuses during the lockdown when public transportation was not available.

Heller et al.'s (2022) study is only about travel impacts of international students at a university in Manchester in the UK that did not take place during the pandemic. Using the International Civil Aviation Organization (ICAO) carbon emissions calculator, they estimated the savings in CO2 emissions by a cohort of 128 master's students who studied fully online from their home countries rather than traveling to and living in Manchester to attend the university in person. The savings accumulated to 969 t of CO2.

In a study from Turkey, Gümrükçüoğlu et al. (2023) calculated the carbon footprint for a campus with over 50,000 students and more than 2,000 staff members for the years 2019 and

2020. In 2020, total emissions were 47% lower, primarily due to reduced electricity consumption. However, emissions resulting from home working were not included in the assessment.

Finally, Prasara-A et al. (2024) assessed the carbon footprint of a university in Thailand, with over 40,000 students for 2015-2021 following TGO (2018) guidelines, covering Scopes 1-3 emissions. From 2015-2019, annual per capita emissions ranged between 0.35–0.37 t CO_2e, with electricity (Scope 2) as the largest source, accounting for 39–41% of total emissions. During 2020–2021, per capita emissions fell to 0.29 t CO_2e—a 17–22% reduction. Scope 3 emissions (water, paper, and staff/student transport) dropped sharply from 83–97 tCO_2e in normal years to 35 t CO_2e in 2020 and 17 t CO_2e in 2021, with student transport being the main contributor in 2020.

Two further studies are included in Phase 2. Louw (2022) did not conduct their own CFA and was therefore discussed earlier in this section. Patella et al. (2025) explored the opportunities of online exams to avoid car trips. The study employed a survey-based case study method with 8,356 responses from students in Italy. The results indicate that 37% of private motorized transport users, including car and motorbike drivers, might consider shifting to rail, while 37% of car users are open to carpooling. Despite this, cars remain the most commonly used mode, accounting for 51% of travel, with an estimated 40 million vehicle-kilometers traveled annually, producing approximately 9,000 t of CO_2 equivalent that could be avoided.

Standards and Operational Boundaries of Recent Carbon Footprint Studies

Regarding the implementation and organizational boundaries of the CFA, a heterogeneous picture emerges. Different reference values for CO_2 emissions are sometimes used, and varying aspects are considered. In some cases, campus operations during lockdowns were included in the calculations, while in others they were not; similarly, the energy consumption of students and staff working from home was sometimes taken into account and sometimes omitted. As previously noted by Valls-Val and Bovea (2021), there is no standardized methodology for CFAs, particularly when different teaching models are taken into consideration.

In line with the GHG Protocol (WBCSD/WRI, 2015), we distinguish between direct emissions, owned or controlled by the organization, and indirect emissions, which are a consequence of the organization’s activities but occur at sources owned or controlled by another party, such as students. To clarify the distinction between direct and indirect emission sources, enhance transparency, and ensure relevance for various types of organizations as well as diverse climate policies and business objectives, greenhouse gas accounting and reporting categorize emissions into three defined “scopes”: Scope 1 direct emissions (e.g., on-campus use of natural gas for heating and cooling), Scope 2 indirect emissions (e.g., purchased electricity), and Scope 3 other indirect emissions (e.g. student and staff transportation, emissions from suppliers, wastewater, water supply, solid waste, and paper used). Valls-Val and Bovea (2021) and Qiu and Dong (2024) found in their reviews, that many HEIs accounted for just Scopes 1 and 2. Calculating other indirect Scope 3 emissions can be challenging because they are not under direct control of the organization.

How do the studies in our corpus compare, looking at the studies from Phase 2? Filimonau et al. (2021) advise caution when comparing current carbon footprint data with studies that are a decade or more old, as substantial progress has recently been made in the sustainability performance of higher education institutions. We find that all nine studies from Phase 2 included Scope 3 emissions related to the impact of ODDE (see also Table 3).

Conclusion and Implications

With this systematic review, we hope to have provided a solid initial overview of the carbon footprint of ODDE. The results are diverse, but considering the great importance of this interdisciplinary topic, only limited research is available to date. Over a period of nearly 25 years, only 17 relevant studies could be identified. Due to this scarcity and the lack of standardized methods for CFA in HEIs, a quantitative aggregation of the impact of ODDE on the carbon footprint through meta-analysis is not possible.

We hold the SusTEACH studies in high regard. However, they already date back quite some time. Filimonau et al. (2021) reiterate the need for further research on the impact of different teaching models:

> […] a dedicated stream of research is necessary to investigate and compare the carbon implications of different teaching/learning modes such as fully offline, blended, fully online. Although this current study has provided some initial evidence towards the GHG emissions of online education, this evidence should be reinforced with a larger number of dedicated case studies. These case studies should target Universities and colleges of different size and specialisation, in the UK and beyond. (p. 143964)

So, is ODDE good for the environment? At first glance, based on the included articles in this systematic review, we would be certainly inclined to answer this question with “yes,” especially in comparison to conventional on-campus learning and teaching. However, the studies also provided insights into certain rebound effects, where energy savings in one area are offset by increased use in another.

Herring and Roy (2002) already wrote about the effects of "dematerialization" in print-based distance education through digitization: “[…] the rapid dematerialization has been compensated for–even definitely overcompensated for–by growth in the demand for computing and communication power” (Hilty, 1999, as cited in Herring & Roy, 2002, p. 3). In the Filimonau et al. (2021) study, it was shown that savings from online learning during the COVID-19 pandemic were offset by the continued operation of the campus, even when the campus was not being used. However, this does not apply to open and distance teaching universities, which generally do not operate a large campus.

Such rebound effects are even more pronounced with new developments in educational technology that involve applications of artificial intelligence (AI). Most prominent among these are groundbreaking advances in transformer-based large language models chatbots, such as ChatGPT. Training and running generative AI applications depend on massive data processing and storage. Data centers require enormous amounts of electricity and water for cooling. It is estimated that a search with ChatGPT uses up to five times more energy than finding the same information with a conventional search engine: “Within years, large AI systems are likely to need as much energy as entire nations” (Crawford, 2024, p. 693).

ODDE relies heavily on digital devices and infrastructure. Each year, billions of electronic devices are manufactured. The production of these devices and their batteries relies on dozens of nonrenewable resources, including scarce metals and rare earth elements. The extraction of these materials involves the excessive use of chemicals and water and the production of toxic waste, leading to pollution and deforestation (Selwyn, 2025). Vanderbauwhede (2021) points out:

> By 2040 emissions from computing alone will be more than half the emissions level acceptable to keep global warming below 1.5°C. This growth in computing emissions is unsustainable: it would make it virtually impossible to meet the emissions warming limit. (para. 1)

That being said, we have seen that ODDE can make a significant contribution to reducing the carbon footprint of HEIs; ODDE can be good for the environment, but further research on the environmental rebound effects of digital education is necessary to enable the responsible and informed selection of technologies.

Until the COVID-19 pandemic, the issue of the carbon footprint in ODDE had largely been absent from the research agenda. With the most recent publications, however, questions concerning the environmental impact of different modes of education have re-emerged. Nevertheless, on-campus education is not usually analyzed in relation to ODDE teaching operations, and the implications of open and distance education practices remain insufficiently understood in this regard. Further research is needed, particularly with regard to developing standardized procedures for measuring the carbon footprint of teaching and learning operations in higher education, as well as for examining rebound effects associated with different delivery modes.

Dedicated ODDE institutions are well represented in the studies discussed here, but they could further strengthen their profiles and positioning in the context of environmental sustainability. Meanwhile, changes in teaching and learning operations, especially delivery modes, remain largely absent from studies of campus-based education. In general, at a time of increasingly strong, selfish national tendencies, when climate change is partly ignored or even denied and many leading economies are shifting their priorities away from climate concerns, this work may feel like swimming against the tide. Nevertheless, such research is of existential importance to a sustainable future.

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*Indicates that the article is featured in the corpus of the review

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