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Decarbonising university operations: strategies and challenges for Higher Education Institutions

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Abstract

Background Universities have significant carbon emissions impact and face pressure to cut their operational carbon emissions around the world. This leads to growing interest of the academic and practice community in effective pathways for carbon reduction within higher education. In this context, the aim of the research is to investigate the strategies for decarbonising university operations and challenges being faced. Drawing from a mixed-method approach, a review of case studies, and a survey involving Higher Education Institutions (HEIs) in nearly 40 countries, it explores the interconnectedness of awareness, cultural and political dimensions, internal institutional structures, and technical approaches in achieving decarbonisation goals.

Results The findings underscore awareness initiatives that enhance understanding of decarbonisation among educators and students in universities, and communities. The case studies as a review of experiences from diverse geographical regions illustrate varying strategies for carbon emissions reduction in HEIs, underscoring the adaptability of decarbonisation efforts across contexts. Additionally, cultural and political factors emerge as key determinants, requiring tailored strategies to navigate diverse contexts and garner public support. Finally, institutional structures, including financial constraints and regulatory barriers, and ageing infraestructure are identified as key barriers to effective decarbonisation efforts.

Conclusions The novelty of the paper resides on the fact that it highlights the need for integrating decarbonisation goals into institutional governance and planning mechanisms is essential for achieving long-term goal of net zero carbon and aligning with the global UN Sustainable Development Goals (SDGs). The study advocates for a holistic approach that considers social, economic, environmental and institutional dimensions in advancing decarbonisation within HEIs, rather than treating emissions as a purely technical issue. The effectiveness of decarbonisation measures is dependent on breaking down chronic structural and financial factors in the implementation, and is substantially supported by institutional practices that promote the engagement of all stakeholders and an open, transparent measurement of its impact. By addressing barriers, HEIs can pave the way for a sustainable and low carbon future while serving as catalysts for broader societal change.

Keywords Higher Education Institutions (HEIs), Climate change (CC), Decarbonisation, Carbon emissions reduction, Sustainability, Sustainable campus

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Introduction: The contribution of universities to climate change

Universities can play a key role in the fight against climate change (CC), particularly through the decarbonisation of their own operations. While universities contribute to climate action through education, research, and innovation, their campuses also function as complex organisations with substantial environmental footprints [12]. Reducing energy consumption, decarbonising transport systems, and applying circular economy principles to manage waste and resources are therefore central operational challenges [74]. By addressing these dimensions, universities can lower their carbon footprint (CF) and demonstrate leadership through practice. Although research and teaching activities contribute to awareness-raising and the development of new approaches to climate mitigation [3, 56, 59], this study focuses specifically on operational decarbonisation, examining how institutional practices, structures, and constraints shape universities' ability to reduce emissions. To reduce carbon emissions, universities can invest in renewable energy, enhance energy efficiency, and minimise waste [35]. Sustainable practices include green procurement, the use of sustainable building materials, and the promotion of eco-friendly transportation options [24, 36]. These efforts may also involve divesting from fossil fuels, reducing waste, and establishing sustainable campus gardens [23, 67, 82].

Sustainable practices in Higher Education Institutions (HEIs) have significant societal impacts [31, 94], as the role of HEIs has shifted from traditional centres of learning to emerging models of sustainable, resilient, and practical governance capable of addressing complex modern challenges [42]. These models center upon long-term ecological and social health (sustainability), the capacity to absorb shocks and adapt to crises (resilience), and practical and effective implementation (practicality). They are typically more collaborative, participatory, and evidence-based strategies than the classic top-down approaches. This entails an integration of diverse stakeholders, data-driven policies, and an ability to be flexible so that institutions can weather disruptions, like CC or pandemics, but are also intentional about stewarding resources and equity for future generations. Consequently, decarbonisation efforts in HEIs encompass multiple domains, including governance and leadership, extending beyond individual engagement. In light of hesitant policy responses from governments, climate leadership by other institutions is vital for maintaining momentum, fostering innovation, and supporting informed climate decisions at a broader scale [8]. Additionally, universities are uniquely positioned to educate students and the wider public about CC and its impacts. Through the provision of courses, research, and degree programmes focused on CC and sustainability, universities contribute to raising awareness and fostering a broader culture of sustainability [58]. They also play an important role in training graduates for emerging green and climate-related sectors and may influence policy through their research activities [52]. However, while these educational and research functions are central to universities' societal missions, the present study does not examine curricular, pedagogical, or policy impacts directly. Instead, it concentrates on operational decarbonisation, analysing how institutional practices and constraints shape universities' ability to reduce emissions in their day-to-day operations.

Through the study of the impacts of CC and proposing solutions, universities can inform governments, businesses, and other organisations on effective decarbonisation strategies [46, 52]. Leading universities across the globe have adopted net-zero strategies to become carbon–neutral HEIs [83]. These strategies include reducing their CF and engaging in carbon offsetting. Greenhouse gas (GHG) emissions metrics are gaining importance in terms of consistency and comparability [30, 57], although the allocation of emissions follows a straightforward scheme: ***Scope 1*** encompasses direct university activities; ***Scope 2*** includes purchased energy; and ***Scope 3*** covers upstream activities such as transportation and investments.

Universities are decarbonising their core business operations and there are various case study examples around the world. Successful examples of universities that have committed to reducing carbon emissions and pledged to become zero-carbon include Arizona State University (ASU). ASU has reduced its ***Scope 3*** emissions by 49% since 2007, and achieved carbon neutrality for ***Scope 1*** and ***Scope 2*** emissions in 2019 through measures such as improving energy efficiency, adopting sustainable building practices, purchasing carbon offsets, and expanding the use of renewable energy. ASU promotes sustainable transportation options and sustainable purchasing policies through specific initiatives [6]. Similarly, the University of California's (UC) commitment to becoming carbon neutral builds on its long-standing leadership in sustainable practices and climate research. Initially, the net-zero target was aimed to be achieved by 2025 [76]; later, the UC administration reset it to 2045 to 'fully decarbonise' university operations. UC's efforts to improve energy efficiency, develop renewable energy sources, and enact strategies to cut carbon emissions are supported by the Global Climate Leadership Council and funding for student-generated projects [77]. The University of Cambridge's 'Cambridge Zero Carbon' aims to harness the University's research capabilities to respond

to CC and transition to a resilient and sustainable future. The initiative focuses on developing greener technologies and materials and addressing every aspect of a zero-carbon future, equipping leaders with the necessary skills [78].

The University of Edinburgh's 'Climate Strategy: Zero by 2040' aims to reduce carbon emissions by 26,838 tCO_2e by 2025 through sustainable travel policies and low-carbon technology investments. The University has already invested over £30 m in low-carbon technology and attracted more than £50 m in climate research since 2010 [79]. Denmark Technical University (DTU) applies the 'Living Lab' concept on its campuses to develop sustainable solutions in new builds, energy supply, and waste sorting [21]. By 2021, DTU had expanded indoor waste sorting into 12 fractions and established a digital recycling exchange. The University prioritises using more wood in building projects and has switched to heating supply from waste management, halving carbon emissions (DTU's Sustainability Policy, 2020–2025).

Lund University's analysis of its climate impact showed that emissions dropped by approximately 25% between 2018 and 2020 although part of this reduction was probably due to mobility restrictions during the COVID-19 pandemic [49, 50]. The University adheres to the Climate Frameworks and aims to reduce GHG emissions to become a climate-neutral HEI by 2045. Measures include revising travel regulations and using climate footprint calculations for necessary interventions [51]. In Canada, Concordia University and the University of British Columbia rank highly in The Times Higher Education (THE) ranking for Sustainable Development Goal (SDG) 13 on Climate Action. Concordia University aims to achieve carbon neutrality by 2040 with a Sustainability Action Plan targeting emissions reduction and sustainable investments [17]. The University of British Columbia's third climate action plan sets an emissions reduction of 45% by 2030 and recognises climate justice as a guiding principle [85].

In Asia, the National University of Singapore (NUS) aims to achieve carbon neutrality by 2030 with key sustainability programmes to mitigate carbon emissions and adapt to CC. NUS has progressively reduced its CF since 2012 and has received the Green Mark Platinum Champion Award [61]. Tsinghua University in China has reduced carbon emissions through energy-saving efforts since 2009, including geothermal wells, solar heaters, and energy-efficient light-emitting diode (LED) lamps. The university promotes sustainable transportation and has made significant energy savings [99].

Despite the growing number of universities that have articulated decarbonisation plans, the literature consistently reports that implementation remains challenging. Commonly cited barriers include limited financial resources, bureaucratic complexity, and institutional inertia, which can slow or constrain progress [65, 92, 94]. High upfront costs associated with renewable energy investments often compete with core academic priorities, while ageing and historically protected buildings tend to be energy intensive and difficult to retrofit [9, 54]. Together, these factors contribute to forms of carbon lock-in, whereby existing infrastructure and decision-making pathways limit the pace of decarbonisation, even where institutional commitment exists [94]. Against this backdrop, analysing universities' operational emissions and the obstacles they face is essential for understanding practical pathways towards decarbonisation.

This study focuses primarily on operational emissions within HEIs, including downstream emissions associated with teaching and research activities, while excluding broader pedagogical, research, or external partnership impacts that are not directly linked to operational carbon emissions. It offers valuable insights into decarbonisation efforts within HEIs in three main ways. While the findings draw on responses from a geographically diverse sample, they should be interpreted as indicative of emerging patterns rather than statistically generalisable results. A key contribution of this study is its identification of common challenges, such as financial constraints, bureaucratic inertia, and, to a lesser extent, the complexity of transitioning to renewable energy sources. These obstacles are commonly reported across HEIs, making the proposed strategies, such as securing green funding, engaging stakeholders, and implementing energy-efficient infrastructure, potentially applicable in diverse institutional contexts. Additionally, the study highlights the importance of integrating sustainability and decarbonisation into institutional governance, suggesting that top-down commitment alone does not suffice for long-term success.

The study also emphasises data-driven approaches, advocating for robust carbon accounting and benchmarking systems. This methodological focus ensures that universities can measure progress accurately and adjust strategies accordingly, a practice that benefits any institution pursuing decarbonisation. Furthermore, the discussion on behavioural change among students and staff underscores the role of education and awareness in fostering a culture of sustainability, reinforcing the idea that HEIs must lead by example. Ultimately, the study's findings extend beyond individual cases, offering scalable solutions for reducing operational CF. Addressing financial, administrative, and cultural hurdles, the study contributes to equipping HEIs with actionable knowledge, making it a significant resource for advancing global sustainability in higher education. Thus, the novelty of the

paper lies in the fact that it studied situations in nearly 40 countries, and touches upon the interconnectedness of sustainability awareness, cultural and political dimensions, internal institutional structures, and technical approaches in achieving decarbonisation goals.

The paper is structured as follows: the next section deals with carbon emissions deriving from university operations. After providing a background, emissions are classified and their calculation outlined. Then, research objectives and this paper's contribution are given. The following section refers to the methods used in this study –i.e., the case studies review and the global survey. Results and discussion are then presented. Descriptive statistics of the survey and sample are depicted along with the analyses from respondents' feedback. Hence, key challenges and strategies to overcome barriers in HEI decarbonisation are offered. Lastly, concluding remarks limitations and future pathways are presented.

Background: Carbon emissions from university operations

HEIs are rapidly transforming and striving to enhance their overall quality in order to climb national and international rankings. However, this drive for excellence often leads to substantial resource consumption and increased GHG emissions, adding to an already overburdened planet [41]. To achieve climate neutrality, HEIs should assess their current environmental performance by calculating their CF to determine their GHG emissions [22]. With an updated assessment, HEIs can formulate policies and implement practices aimed at reducing emissions and promoting sustainability [18]. The CF is a valuable decision-making tool, offering a concrete basis for comparing the environmental impact of institutional activities with those of other academic institutions. As such, it is essential for HEIs to take the lead in measuring, monitoring, and reducing their CF as part of their role as sustainable organisations [86, 87].

Despite the fact that various universities are developing plans to minimise GHG emissions, only a small minority record and publish complete carbon inventories. In some cases, reports are only available in local languages, limiting global accessibility [30]. Although comparing emissions and drawing firm conclusions can be difficult, researchers have attempted to capture and analyse available data. Based on a review of the literature, Fig. 1 highlights these efforts by presenting per capita emissions per year rather than total emissions, from a sample of universities. This is due to the wide variability in measurement methods and institutional capacities. The educational process itself contributes to environmental impacts through construction projects and day-to-day operations [68]. HEIs operate as complex ecosystems [28], and their functions—education, research, governance, and enterprise—all influence their GHG emissions. Teaching activities, in particular, have a significant impact, requiring not only physical infrastructure such as libraries and lecture theatres, but also a wide range of support services, including wellness, sports, social services, retail, and food and beverage outlets to support student wellbeing [69]. Figure 1 also illustrates the significant variation in per capita carbon emissions among universities, even within the same country. For example, in the United States (US), per capita emissions range from 2.9 to 8.2 tons CO_2, making it difficult to draw valid conclusions at the national level.

Carbon emissions classification

CF calculation involves categorising emissions and assigning them to specific ***Scopes***. One of the most widely adopted frameworks for this is the GHG Protocol Corporate Standard, developed by the World Business Council for Sustainable Development and the World Resources Institute [93]. This standard enables institutions to define their operational boundaries for 'scoping' emission sources, helping to avoid double counting of emissions [90]. Figure 2 illustrates the designated emission categories in relation to the operations of educational institutions, as outlined by the corporate GHG Protocol Standard.

Three main ***Scopes*** can be distinguished. ***Scope 1*** refers to emissions directly caused by on-site fossil fuel combustion, such as for electricity, heat, or steam production, as well as emissions from transportation, materials, waste, and members of the campus community. It also includes unintentional leaks. ***Scope 2*** addresses indirect emissions associated solely with the production of purchased energy—emissions generated during the production of imported electricity, heat, or steam. ***Scope 3*** encompasses a broader range of indirect emissions, including those from business travel, outsourced activities, and waste management [38, 90]. Although GHG emissions are grouped into these three ***Scopes***, fully attributing and accounting for the total emissions produced by an organisation can be highly complex. ***Scope 1*** and ***Scope 2*** emissions are generally easier to identify and calculate, whereas ***Scope 3*** emissions vary significantly depending on the institution [18]. Trends in emissions by ***Scope*** (expressed as percentages) show that, in most cases, emitters in developed countries report a higher proportion of emissions in ***Scope 1*** (Fig. 3). Furthermore, a higher share of emissions in ***Scope 1*** typically corresponds with a lower proportion in ***Scope 3***.

Overall, the analysis reveals significant variation in the distribution of emissions across the three ***Scopes***. In most cases, institutions in developed countries report a higher

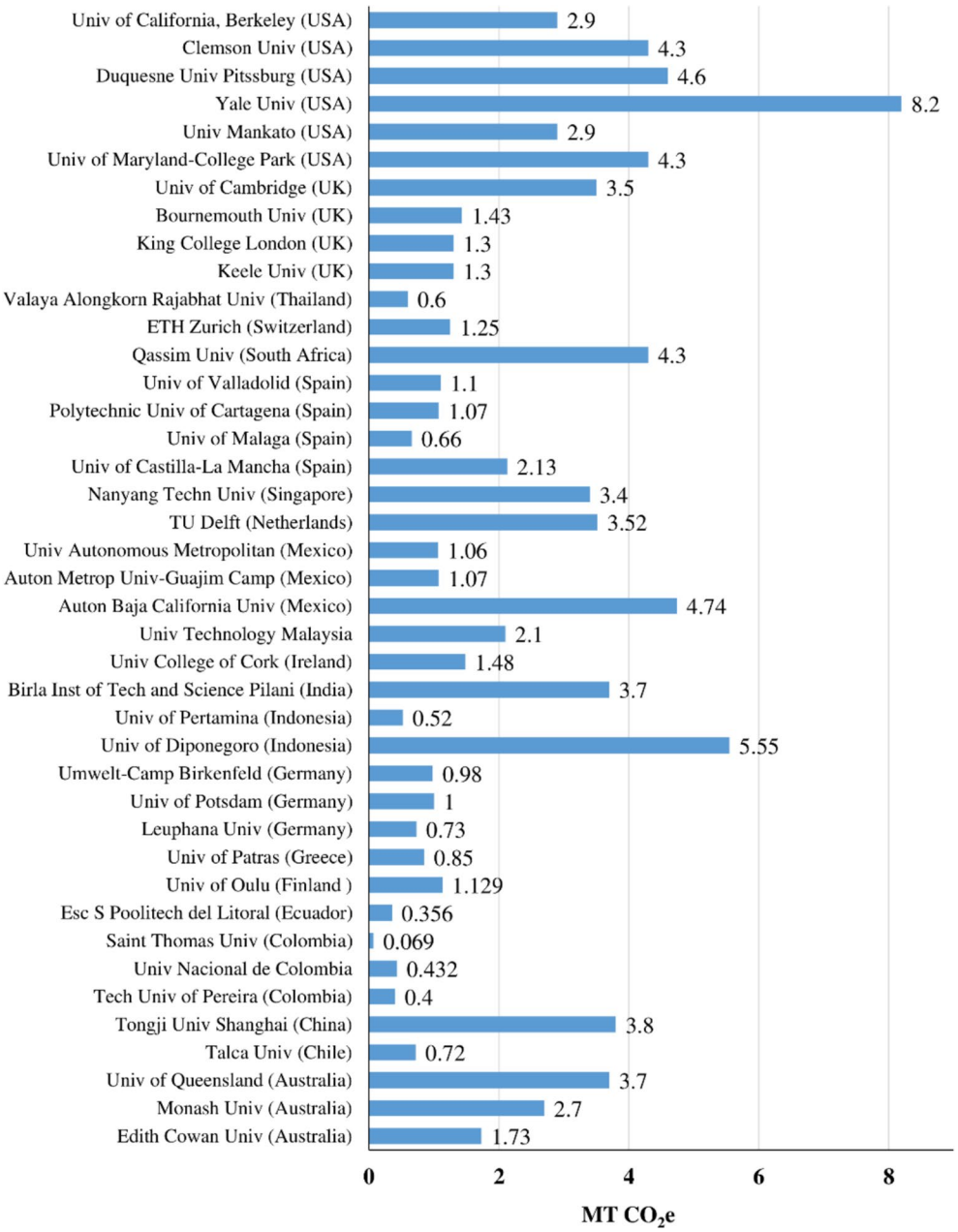

Fig. 1 Annual HEIs' emissions per capita* per year (metric tons CO_2e) (years 2013–2022). *denotes per capita (as the sum of students and employees/staffs/residents). Source: authors, based on data from [2, 15, 86].

share of ***Scope 1*** emissions, reflecting direct energy use for heating, transport, and on-site operations. ***Scope 2*** emissions, mainly from purchased electricity, account for a moderate share, while ***Scope 3*** emissions (indirect sources such as commuting and procurement) vary widely depending on data availability and reporting practices. To simplify comparison, Table 1 summarises the main ranges observed across the reviewed institutions.

A compiled dataset on CO_2 emissions across operational categories from diferent universities revealed a wide range of values (Table 2) [9, 15, 16, 19, 22, 29, 48, 60, 71, 84, 88, 98] . More than 20 categories were identified as operational sources of CO_2 emissions, although not all were consistently reported across institutions (Table 2). The primary sources of emissions included: staff and faculty air travel (221.6–74,003.8 mt CO_2), boilers and heating systems (2,143–34,547 mt CO_2), food, canteen, and

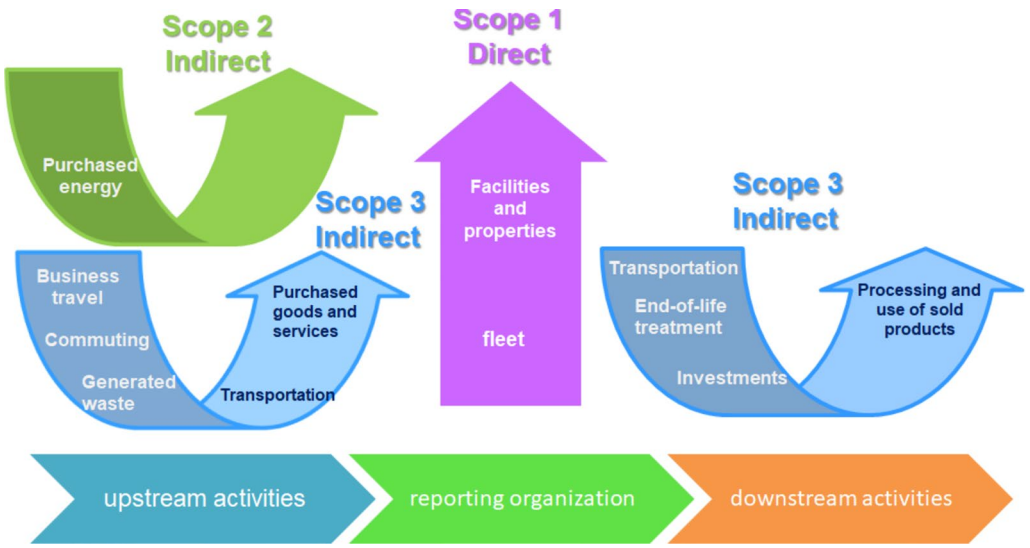

Fig. 2 ***Scopes*** of emissions according to the GHG Protocol Corporate Standard. Source: authors, based on data from WRI and WBCSD [93]

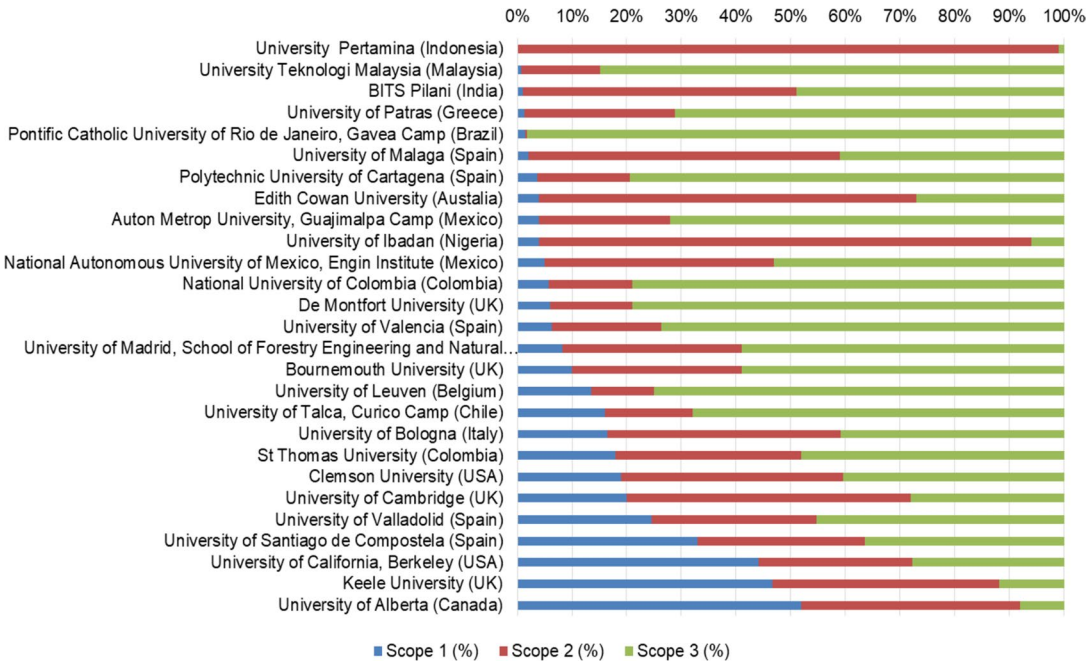

Fig. 3 Classification of HEIs emissions by ***Scope***. Source: authors, based on data from Cano et al. [15]

catering services (30.56–18,463.23 mt CO_2), wastewater treatment (10.2–13,732.31 mt CO_2), trains, buses, and other land transport (4.21–11,194 mt CO_2), leakages and refrigerants (3.5–6,729 mt CO_2), commuting by students and staff (3.42–6,654 mt CO_2), electricity use (0.678–2,938 mt CO_2), travel-related emissions (0.07–1,303.94 mt CO_2), water usage (0.0462–1,160 mt CO_2), solid waste (0.027–745.58 mt CO_2), and information technology (IT) and paper-related consumption (0.0016–504.65 mt CO_2). Correlation analysis among the emission ***Scopes*** showed weak to moderate relationships: ***Scope 1*** and ***Scope 2*** ($r=0.60$), ***Scope 1*** and ***Scope 3*** ($r=0.31$), and ***Scope 2*** and ***Scope 3*** ($r=0.55$).

Carbon emissions calculations

In recent years, analytical methods for calculating carbon emissions in HEIs have gained importance, and various approaches have been developed. However, progress in

evaluating the broader environmental impact of these institutions remains limited [41, 60]. Traditionally, an organisation's CF is calculated using either the process-based life cycle assessment (LCA) approach, which estimates emissions at each stage of a system, or the environmentally extended input–output (EEIO) approach, which links economic consumption with environmental impacts. A hybrid method—environmentally economic input–output life cycle assessment (EIO-LCA), also referred to as hybrid-LCA—combines process-LCA and EEIO to leverage the strengths of both models [22]. Several universities have adopted this hybrid method successfully due to its flexibility in integrating best practices and its adaptability to the specific operational characteristics of individual institutions [38]. Key regulatory frameworks cited in the literature include the GHG Protocol [27], ISO 14064-1 [32], ISO/TR 14069 [33] , PAS 2050:2011 [11], and PAS 2060:2014 [10, 18] (Table 3). Across these frameworks, six main properties can be distinguished: (1) the scope of emissions considered (organisational vs product-specific; (2) the methodological basis (life-cycle vs operational accounting; (3) the degree of verification required; (4) the level of prescriptiveness and flexibility; (5) the intended audience or organisational type; and (6) the link with international reporting initiatives. This typology provides a clearer overview of how the standards collectively shape carbon accounting practices within HEIs. These frameworks provide essential guidance for assessing and managing GHG emissions, supporting universities in their efforts to reduce their CF.

The GHG Protocol Corporate Standard is generally preferred for calculating emissions within HEIs [37, 60, 86]. This standard clearly defines the requirements for emissions in ***Scopes 1*** and ***2***, but ***Scope 3*** has fewer requirements, permitting the inclusion of selected indirect emissions that are not energy-related. As a result, university carbon emissions are often calculated based on individual experiences, published case studies, or self-defined rules, due to the absence of a universally recognised standard for universities [30, 38]. Accurately and efficiently calculating the CF of HEIs requires specialised assessment tools. Existing tools for CF calculation vary in terms of inputs (source and emission factors) and outputs (results) and are not universally customisable to accommodate universities worldwide, including ***Scopes 1***, ***2***, and ***3*** [30, 86]. To address this gap, Valls-Val and Bovea [87] introduced CO2UNV, a CF assessment tool specifically designed for universities. This fully configurable tool can accommodate any case study, irrespective of emission sources and factors. Currently, CO2UNV exists as an Excel prototype but requires further development into a user-friendly online tool [87]. The literature review reveals that the CF evaluation process offers valuable insights into the various emissions categories that can be included or excluded. However, significant differences in results across institutions complicate comparisons. Different universities employ individual methods, underscoring the need for a unified approach and standardised guidelines. Such standardisation would enhance comparability and enable the effective evaluation of emissions reduction policies and practices [38]. Therefore, the creation of a globally accepted tool, specialised for HEIs, is crucial to standardise emissions measurement and facilitate comparative analysis.

Table 2 Range of CO_2 emissions from different operations at HEIs

Operation	Range (mt CO_2)	
	Min	Max
Flights	221.6	74,003.8
Heating	143	34,547
Catering, canteen and restaurant services	30.56	18,463.23
Wastewater treatment	10.2	13,732.31
Train & other land transport	4.21	11.194
Fugitive emission & refrigerant	3.5	6,729
Commuting service	3.4167	6,654
Electricity usage	0.678	2,938
Travel-related emissions	0.07	1,303.94
Water use	0.0462	1,160
Solid waste generation	0.027	745.58
Telecommunication, Internet & paper use	0.0016	504.647

Source: authors, based on data from Letete et al. [48], Gu et al. [29], Ullah et al. [84], Clabeaux et al. [16], Dagliouglu [19], El Geneidy et al. [22], Naderipour et al. [60], Varón-Hoyos et al. [88], Zayit et al. [98], Cano et al. [15], Samara et al. [71], and Battistini et al. [9]

Table 1 Summary of typical minimum, maximum, and average proportions of institutional GHG emissions by ***Scope***, based on data from the reviewed universities (see also Fig. 3)

Emission scope	Typical minimum (%)	Typical maximum (%)	Mean/median (%)	Main sources
Scope 1	35	65	≈ 50	Direct fuel use, campus transport, heating
Scope 2	15	40	≈ 25	Purchased electricity and heat
Scope 3	10	50	≈ 25	Commuting, procurement, waste, investments

'Typical' minimum and maximum values refer to the lower and upper bounds observed after excluding extreme outliers reported in a small number of cases, in order to provide indicative ranges rather than absolute extremes. Source: authors, based on Cano et al. [15]

Table 3 Some regulatory frameworks and international guidelines for the calculation of organisational carbon emissions. Source: authors

Framework	Description
The Greenhouse Gas Protocol Corporate Standard	A true and fair calculation and description of emissions through the use of standardised approaches and principles simplifies and reduces the cost of compiling a GHG inventory, provides organisations with information to build an effective strategy to manage and reduce GHG emissions, and increases consistency and transparency in GHG accounting and reporting. This is a standard written not only for businesses that develop a GHG inventory, but also for other organisations with operations that cause GHG emissions, e.g., NGOs, government agencies and universities [27]
ISO 14064–1:2006	It clarifies how organisations can develop inventories of the sources of such emissions and identify actions to reduce them while making it easy to audit and compare, facilitating assessment of which actions are working, and which are not [32]
ISO/TR 14069:2013	For direct and indirect GHG emissions, ISO/TR 14069:2013 outlines the principles, concepts, and methods [33, 34]
PAS 2050:2011	Assesses the cradle-to-gate GHG emissions of products and services throughout their life cycle. Identifies the system boundary, identifies the sources of GHG emissions associated with products within the system boundary, specifies the requirements for analysing the data, and describes how results are calculated. While this PAS (Publicly Available Specification) addresses global warming as a single impact category, it does not provide an indication of the overall environmental impact associated with life cycle GHG emissions, as may be determined by another type of environmental impact assessment [11]
PAS 2060:2014	In addition to verifying that an organisation is carbon neutral, British Standards Institution (BSI) can demonstrate this for individual activities, products, services, buildings, projects, or events within the business [10]

From literature to research objectives

The reviewed literature demonstrates that while numerous frameworks and tools exist to calculate institutional CFs, there remains limited understanding of how universities translate these standards into effective operational strategies and what are the barriers with ways to address them. Previous studies highlight that institutional culture, leadership commitment, and stakeholder engagement are decisive factors influencing the success of decarbonisation initiatives in HEIs [9, 43, 54]. These insights suggest that organisational and governance dimensions are as critical as technical ones.

Building on these insights and gaps, this study aims to identify how HEIs integrate decarbonisation within their governance and operational structures, and what barriers persist. The findings from the literature therefore directly inform the methodological approach combining a literature-based review of case studies with a global survey.

Methods

In order to shed some light on decarbonisation efforts in HEIs, this study employs a mixed-methods approach, which complements the analysis and literature review provided in previous section. It has reviewed and analysed a set of case studies based on the literature, from a set of universities implementing sustainability initiatives. This is complemented by a survey to identify key sources of carbon emission in university operations and barriers to implementing decarbonisation measures to handle them.

The use of these two methods facilitates the evaluation of policy and strategy frameworks and the use of tools to support decarbonisation in HEIs. By integrating empirical data with practical case study examples review, the study provides a replicable methodology for universities to assess and reduce their carbon emissions systematically. Both methods are now described in turn.

Case studies

The methodology followed in this study took into account Yin's [97] approach to case study research. A total of 22 publications featuring single or multiple case studies were selected with the goal of gathering evidence to illustrate the best practices in decarbonisation efforts at universities worldwide. The entire team of authors, all experts in the field of sustainability and decarbonisation, collaborated throughout the process to ensure a robust selection of case studies for the review of experiences which is inclusive. To identify relevant case studies, the team utilised reputable academic databases, including Web of Science, Scopus, and Google Scholar, employing search terms such as 'green campus', 'sustainable campus', 'greenhouse gas emissions', 'carbon footprinting', 'climate action', 'greenhouse gas inventories', and their appropriate combinations. In this study, the term "case studies" is used to refer to literature-based analytical exemplars rather than in-depth institutional case studies grounded in primary organisational data or institutional CF reporting. The selected cases are drawn from peer-reviewed publications that document decarbonisation practices in HEIs, and they are used to illustrate common approaches, barriers, and enabling factors across different contexts. Analytical depth is achieved through cross-case comparison and synthesis of reported experiences, rather than through institutional triangulation with additional documentary sources. This approach was adopted to ensure consistency and comparability across cases and

to remain aligned with the exploratory and mixed-methods design of the study.

The screening process involved reviewing the titles and abstracts of identified publications to ensure a broad geographical representation of the cases selected. This step was carried out collectively by the authors, ensuring that the chosen publications reflect diverse global perspectives. The final set of case studies was selected through consensus among the authors, with the aim of ensuring a balanced representation of exemplary cases, rather than pursuing a comprehensive or systematic literature review. The focus was on identifying and presenting cases that provide valuable insights into best practices, barriers faced by institutions, and recommendations for overcoming these challenges. This selection process benefited from the collective expertise of the authors, who carefully evaluated each case's relevance to the study's objectives.

Through the analysis of these selected case studies, the study aims to develop a comprehensive understanding of the challenges faced by various institutions, as well as the strategies they have implemented. By focusing on successful practices and areas where improvements are needed, the findings offer practical insights that can guide other universities in their decarbonisation efforts. This integrated approach not only fosters a cohesive discussion but also encourages the adoption of proven strategies while recognising the unique contexts of different HEIs.

Survey on barriers to decarbonisation in higher education

To complement the review and analysis of case studies, a survey was used, aimed at investigating the barriers to decarbonisation in higher education, with a particular focus on reducing CO_2 emissions from university operations. The survey was run in parallel to the case studies, and developed collaboratively by the research team, leveraging the expertise of all co-authors. The questions were original and specifically designed for this study, based on the authors' prior research and experience in sustainability and decarbonisation within HEI underpinned by the literature.

To ensure the instrument's clarity, consistency, and relevance, it underwent a rigorous validation process, which included iterative consultations with the entire research team. A pretest was also conducted with field experts to assess the survey's effectiveness. Their feedback played a critical role in refining the wording, structure, and response options, ensuring that the questionnaire was both comprehensive and user-friendly. Following these revisions, the final version of the survey was distributed for data collection. Responses were gathered over a 6-month period, from May to November 2023, allowing ample time to capture diverse perspectives and experiences from participants across different institutions.

Survey research is, in most cases, the best means of collecting original data on populations that are too large for direct observation [7], and it has been developed and widely applied in university and educational contexts [47, 63]. Our methodological approach ensured that the survey was well-suited to addressing the research objectives and gathering meaningful insights into the challenges faced by universities in their decarbonisation efforts. The questionnaire design builds on previous survey-based work by the authors [44, 45], drawing on established approaches commonly used in studies of sustainability and decarbonisation in HEIs. The team members sent it to their available expert network contacts and email lists. A total of 136 questionnaires from 39 countries have been received. Incomplete or no answers were discarded.

The questionnaire was structured in three different sections:

i. Background Information. The first section of the survey included questions designed to characterize the sample, covering the institution's country, size, campus structure, nature and profile, as well as the respondent's position within the university and their gender.
ii. Assessment of the Institution's Commitment Towards Decarbonisation. The second section focused on specific aspects of the institutions' decarbonisation efforts, covering the following topics: Energy (reducing energy consumption and GHG emissions on campus, and using renewable energy sources); Transportation and Mobility (reducing carbon emissions from student and staff commuting, promoting sustainable campus mobility initiatives, and supporting sustainable business travel practices); Buildings and Infrastructure (certification of sustainable buildings, facility retrofits, and energy efficiency); Food and Waste (reducing carbon emissions in university dining services, tracking emissions related to food production and transportation, minimizing food and packaging waste, and managing waste disposal and recycling); and Laboratory Operations (chemical waste management and energy efficiency).
iii. Challenges and Barriers to Decarbonisation in Higher Education. The final section of the survey focused on identifying the challenges and barriers encountered by HEIs in the decarbonisation process, as well as exploring opportunities for improving their performance.

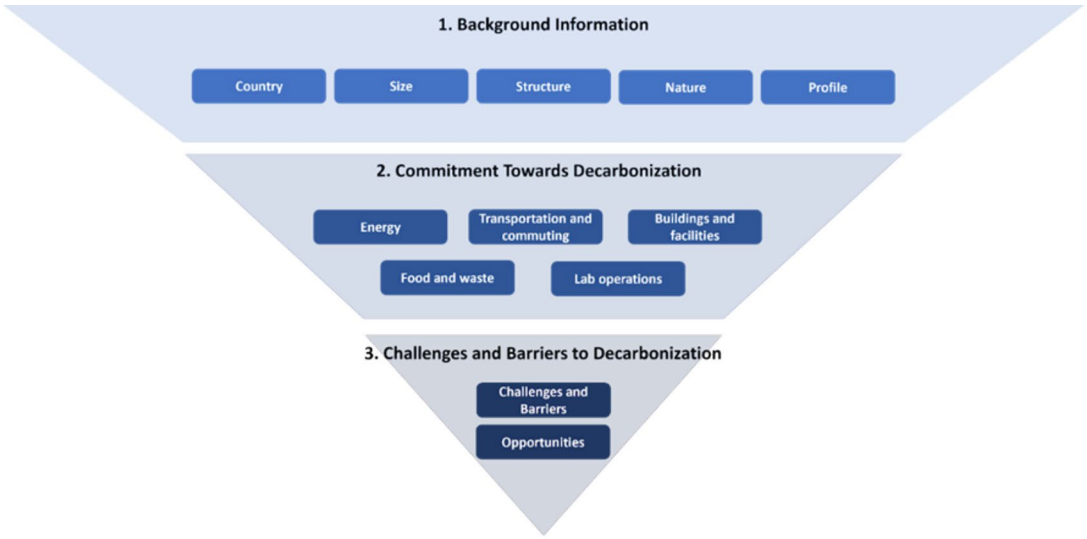

Fig. 4 Survey design. Source: authors

Figure 4 presents the survey design, outlining the structure and key sections of the questionnaire.

The questions used to describe the characteristics of the HEIs and respondents were analysed using descriptive statistics. This approach provides a concise overview of the sample composition, focusing on key demographic and institutional characteristics. As the analysis is based on average values, the results are intended to illustrate general tendencies within the sample rather than the full distribution or variability of responses. Accordingly, the descriptive analysis serves to contextualise the findings within the broader landscape of higher education.

The questions related to barriers were designed using a Likert-like scale. Responses were assigned numerical values (to a very great extent = 5; to a great extent = 4; to a moderate extent = 3; to a little extent = 2; not at all = 1), and average scores were calculated. In addition to the Likert scale, respondents were able to indicate additional barriers or challenges through the "other aspects" response option, thereby capturing contextual elements not included in the predefined categories and enriching the interpretation of the results.

Results and discussion

This section presents and discusses the results gathered from the case studies and survey.

Case studies

The case studies examine peer-reviewed research related to decarbonisation in higher education institutions, with a focus on key themes, best practices, and barriers to change. Table 4 provides a structured overview of the analysed case studies, summarising their geographical scope, thematic focus, methodological approach, and the main decarbonisation practices and barriers identified, thereby supporting comparative and cross-case analysis.

As part of efforts to advance the SDGs, greater emphasis on sustainability issues in higher education programmes [73] will contribute to raising awareness about decarbonisation and the pursuit of carbon neutrality within HEIs [42]. One example of such an initiative is the 'Carbon Literacy Training' offered by Nottingham Trent University [62], which provides educators, communities, organisations, and students with essential carbon literacy knowledge [42, 62]. The training equips participants with the necessary information to make informed decisions regarding climate solutions, ultimately contributing to a brighter, more sustainable future.

Other studies highlight awareness as a crucial element in implementing action. For instance, Campos-Guzmán et al. [14] (**#14**) and Rojas-Vargas et al. [70] (**#12**) found that a lack of interest in food waste often results in significant quantities of food being left uneaten, suggesting that capacity-building is key to improving responses to food waste issues. Zheng et al. [100] (**#17**) identified that behaviour changes in air conditioning usage, food consumption, and the adoption of electric bicycles are important factors in reducing emissions. Additionally, Bulunga and Thondhlana [13] (**#6**) concluded that providing energy-saving tips, combined with regular feedback and incentives, can result in reductions in energy use in university residences. Beyond knowledge and awareness, some studies highlight the significance of cultural and political factors in driving climate action within HEIs. Battistini et al. [9] (**#22**) recommend that

cultural differences be taken into account in multi-campus universities.

Political factors also play an important role in decarbonisation efforts. For instance, Franco et al. [26] recommend assessing the availability and willingness of municipal governments to participate in developing transition teams. Furthermore, these authors suggest that within HEIs, transition teams should be empowered to make necessary changes and implement new strategies.

The internal structure of universities is also crucial to decarbonisation efforts. For example, some studies report challenges in obtaining data on carbon emissions necessary for calculating CF or GHG inventories. Battistini et al. [9] (**#22**) highlight that refrigerant gases, in particular, present significant difficulties. This may also include aspects related to ***Scope 3*** emissions where the university may not have control. Maistry and McKay [54] (**#4**) note that personnel can either facilitate or hinder implementation, recommending actions such as hiring, training, and raising awareness, with the appointment of energy champions at the highest organisational levels. Similarly, Palanichamy and Goh [65] (**#5**) suggest a phased approach to implementing photovoltaic (PV) systems across campuses.

From a technical perspective, several methods have been tested to prioritise actions for decarbonisation. For example, Campos-Guzmán et al. [14] (**#14**) employed the Analytical Hierarchy Process (AHP) to address financial constraints in the simultaneous installation of photovoltaic systems. According to Timmons and Weil [81], the main decarbonisation strategies for HEIs, in line with CC mitigation, involve renewable electricity generation, electrification of end uses, and energy efficiency, with the optimal combination of these strategies being essential. While the complexities of decarbonisation are acknowledged, the authors emphasise that the most crucial benchmark for HEIs is the expected cost of grid-purchased carbon-free electricity.

They suggest that the focus should be on achieving decarbonisation targets at the lowest possible cost, rather than pursuing financial rewards from reducing fossil fuel use. This represents a significant shift in objectives for many HEIs and calls for a new approach to institutional planning, which must now account for phasing out fossil fuel-dependent infrastructure. Consequently, greater investments in energy efficiency may be justified when considering total decarbonisation rather than individual interventions based solely on fossil fuel savings. Indeed, while individual actions can contribute to energy savings, they are insufficient to achieve full decarbonisation [25]. Franco et al. [25], in their study of student energy-saving behaviour at PXL University of Applied Sciences in Belgium and the University of Caxias do Sul in Brazil, identified three key dimensions influencing students' energy-related attitudes: the roles of citizens, scientists, and government, which together explained 65.5% of the students' energy-related attitudes. The study also revealed three dimensions of sustainable behaviour—consumption of environmentally friendly goods, money-motivated behaviour, and home energy conservation—which together explained 64.5% of the students' energy-related behavioural intentions. The authors argue that these findings underscore the need to engage key stakeholders in promoting decarbonisation efforts within HEIs, facilitating societal progress. Carbon lock-in, the continued reliance on fossil fuel energy systems despite the availability of low-carbon alternatives, presents a major obstacle to achieving carbon neutrality in HEIs, even when there is public commitment to sustainability.

The long-term costs associated with carbon lock-in, such as the expense of offsetting locked-in emissions, cannot be ignored and must be factored into decision-making [94]. A study by Horan et al. [31] (**#10**), which aimed to develop a method for quantifying the decarbonisation potential of technologies at Irish Higher Education Campuses (HECs), revealed that decarbonisation methods involving power generation could result in significant carbon savings. The study also highlighted the potential for reducing carbon emissions related to water delivery. Findings indicated a strong correlation between the gross internal area (GIA) of HECs and roof area, while the correlation with parking area was less significant. This research suggests that urban form plays a more important role in determining the parking area at HECs. The methodology, which includes the use of open carpark areas, could also be applied to city-scale investigations, promoting decarbonisation transitions beyond campuses.

Research on internal carbon prices (ICPs) in use at 11 United States HEIs revealed a growing applicability of these tools [8] (**#11**). The study found that both proxy carbon prices and carbon charges are already being implemented in several US HEIs, signalling their potential to drive institutional change by encouraging the adoption of low-carbon options. These tools help promote transparency, standardise decision-making, and drive cost-effective use of resources, ultimately supporting HEIs' decarbonisation goals, such as the adoption of net-zero building standards and the promotion of electric vehicle use. In the context of decarbonisation, the concept of "smart campuses" plays an important role in reducing carbon impacts [40].

HEIs in the United Kingdom and worldwide are increasingly integrating smart services and Information and Communication Technologies (ICT) into their daily operations. A key benefit of distributed energy generation is carbon

Table 4 Practices, barriers and suggestions from the case studies. Source: authors

Reference	Study country	Topics	Best practices	Barriers	Additional suggestions for implementation
#1. De Villiers et al. [20]	New Zealand	Carbon sequestered in the trees on a university	Quantification of portion of emissions that are mitigated by CO_2 sequestration in the trees	Cost of quantification and acting to mitigate emissions	To couple overseas travel reduction with increase in sequestration
#2. Maistry and Annegarn [53]	South Africa	Using energy profiles to identify university energy reduction opportunities	Study of energy consumption patterns at a university to find savings alternatives Studied patterns include details on weekdays in-session, out-of-session and recess. The study determined most active, quieter and dormant periods	Missing and inconsistent measurements lead to need of interpolation	Opportunities for reduction, as proposed: detailed metering, base load management (base load is 60% of peak) and reduction, optimization of cooling, use of motion sensors, timers and detection devices Providing feedback to users can motivate to participate, including encouraging to switch off computers, heaters, air conditioners and other appliances when not required
#3. Vásquez et al. [91]	Chile	Carbon footprinting and proposals for reduction	Carbon footprinting and study of potential actions in four scenarios	Resistance to change behaviour, economic and legal factors potentially affect implementation of actions	Most effective scenario for improvement is students using bikes instead of motorized transport Other actions regarding transport are proposed It also considers building lighting improvements
#4. Maistry and McKay [54]	South Africa	Promoting energy efficiency	Study of energy consumption management ("demand side management")	Historically low energy prices, lack of knowledge and understanding, institutional barriers and resistance to change, lack of investment confidence Demand side management requires managerial buy-in, capacitated operational personnel and money	Energy demand side management to be implemented in phases Personnel can either support or hinder implementation Actions in hiring, training and awareness needed Establish energy-champion at the highest organization level
#5. Palanichamy and Goh [65]	Malaysia	Not specific, but the work is essentially on energy consumption	Photovoltaic system	High costs are a key challenge to implementing energy and environmental sustainability measures on campus grounds	To implement in four stages, one building at a time

Table 4 (continued)

Reference	Study country	Topics	Best practices	Barriers	Additional suggestions for implementation
#6. Bulunga and Thondhlana [13]	South Africa	Energy consumption at students' residence	Listening to students to understand behaviour	Safety and security hazards when switching lights off Laziness and convenience to practice known energy saving procedures Heaters not able to warm rooms fast enough (keep them on when room is empty) Inappropriate circuit switches (shared switches for more than one device or lighting)	Information provision of energy saving tips (e.g., visual tips) combined with regular feedback and incentives can result in energy-use reductions in university residences Provision of more appropriate buildings, equipment and installations
#7. Park and Um [66]	South Korea	Using unmanned aerial vehicle near infra-red and visible signatures to differentiate carbon sinks vs carbon sources on university campuses	Proposal of a framework to differentiate quantitatively carbon sinks and carbon sources on university campus grounds	Difficulties in determining the spatial resolution for the UAV camera	Near infra-red and visible signature technology has the potential to be used as an approach to measure and compare university campus carbon sinks vs sources
#8. Sangwan et al. [72]	India	Use of life cycle assessment to measure university CF	Measuring the CF of an Indian university campus to be used as a base model for other institutions	Availability of data Collecting the available data to determine the GHG emissions	There is a need to formula better policies to reduce emissions on campus particularly in relation to energy consumption, commuting and travel
#9. Abu Qdais et al. [1]	Jordan	Environmental sustainability features in large university campuses	Wastewater reuse On-site incineration of medical waste Minimizing the number of trips made by university vehicles by merging the travel trips of employees and students; fixing GPS devices to track and control the movement of vehicles off campus; offering free shuttle buses for students and employees to move on campus; and phasing out older vehicles in the fleet	Lack of regulations to manage waste streams Low cost of landfills	To use win–win strategies to match sustainable actions and payback To improve awareness of university community with campaigns
#10. Horan et al. [31]	Ireland	Supply chain emissions and purchased electricity emissions	Building integrated photovoltaics (PV), micro-wind turbines, rainwater harvesting and ground mounted PV	Gaps in methods to estimate deployment potential	Novel method to estimate decarbonisation technology deployment potential at higher education campuses

Table 4 (continued)

Reference	Study country	Topics	Best practices	Barriers	Additional suggestions for implementation
#11. Barron et al. [8]	USA	Internal carbon pricing (ICP) in 11 institutions	Using ICP for capital projects, department budgeting, revenue neutral across campus	Choosing the right ICP tool support from faculty, staff, and students for measurement and analytics, decision-making, record-keeping, behavioural change, and communications, administrators willing to work to bring climate considerations more fully into decision-making and engage in the learning process Other policies and criteria could be seen as more simple than ICP	HEIs size and structure are not relevant barriers ICPs have the potential to drive societal climate-decision making policy at large scale. As climate policy grows, it is essential to understand where carbon pricing actually works and where alternative strategies are more successful within HEIs, allowing better informed climate decisions and learning
#12. Rojas-Vargas et al. [70]	Costa Rica	Not specific	Measuring food waste in a campus and showing relation with different practices and population	Lack of interest on the food waste theme by students and other users of restaurants	Awareness campaign Capacity-building for restaurant personnel to be awareness agents
#13. Yañez et al. [95]	Chile	CF estimation	Progressive implementation of CF measurement in multi-campus HEI	Control of ***Scope 3*** emissions	Applying an overarching energy management system to decrease the total energy consumption Incentivize travel by public transportation Incentivize carpooling with privileged parking places Encourage traveling by bike Gather data on green areas to account for sequestration
#14. Campos-Guzmán et al. [14]	Mexico	Use of structured decision tool to choose priority investments in photovoltaic energy at a university	AHP-RIM to define the order of installation of photovoltaic systems in the creation of sustainable university campuses	Not referred	When it is not possible to start all photovoltaic projects at once, a structured decision method based on AHP is possible to use The interviewed experts prioritized technical aspects such as initial cost, system power and % of demand covered by PV over education, lost / occupied area and local project influence
#15. Varón-Hoyos et al. [88]	Colombia	Assessing the CF	Senior management was involved with the project and results	Not referred	Improved management of water, electricity and the mobility of students and teachers could have reduced the emissions

Table 4 (continued)

Reference	Study country	Topics	Best practices	Barriers	Additional suggestions for implementation
#16. Yasuoka et al. [96]	Brazil	IoT solution for energy management and efficiency	It proposes the use of IoT to cut energy consumption from air conditioning It describes hardware and software needed, online monitoring and other features	The initiative requires the engagement, awareness and actions from users combined with investment in energy efficiency to achieve an efficient use of this type of equipment	Use of IoT can provide valuable information for strategic initiatives in energy efficiency projects and research and development programs based on practical experience
#17. Zheng et al. [100]	China	Energy and food consumption	Using questionnaires and machine learning to identify main behaviours associated to emissions	Large population living in the campus and lack of energy saving measures	Making behaviour changes in air conditioning, food and electric bicycles were the most important factors
#18. Adeyeye et al. [2]	Nigeria	CF assessment and mitigation scenarios	CF assessment, scenarios proposal indicators choice	Addressing datasets under ***Scope 3*** benchmarking results	To address the impact of the daily activities of members of staff and students Need for behavioural change To define framework to address indirect emissions sources
#19. Cano et al. [15]	Colombia	CF	Using CF as a baseline for emissions reduction strategies	Control of indirect emissions Benchmarking between campuses	Using CF as a baseline for emissions reduction strategies
#20. Tian et al. [80]	USA	Sustainable design of campus energy systems toward climate neutrality and 100% renewables	Sustainable design of carbon–neutral energy systems is addressed, considering earth source heat, lake source cooling, on-site renewable electricity generation, and sustainable peak heating systems Electricity is mainly purchased from the local electric grid with on-site generation from renewables	Lack of a more detailed energy profile, like hourly instead of monthly, can affect optimization results	The results can be applied to other campuses, towns, cities, and regions with similar climate conditions, especially the temperature by modifying some case-specific dimensions, such as the local availability of renewable energy sources
#21. Whitfield et al. [92]	Spain, Switzerland, UK, Italy, The Netherlands, Germany	To assess the steps that global health institutions are taking to cut their own operational GHG emissions and to identify the aids and impediments to attaining decarbonization objectives	An essential success component consists in including all staff, researchers, and students in the institution's sustainability approach	Significant emissions from air travel Poor energy efficiency of historic and protected buildings Resistance to change and adopting more sustainable ways of working Urban budgets that impede long-term agenda	Engaging people Working with collaborators Taking concrete and rapid action

Table 4 (continued)

Reference	Study country	Topics	Best practices	Barriers	Additional suggestions for implementation
#22. Battistini et al. [9]	Italy	Transportation (year 2018) IT procurement (year 2020)	Use of GHG protocol, the ISO 14064, and the ISO/TR 14069 guide to calculate CF Multi-campus university approach Survey on transport (commuting) Study of very different years (2018 and 2020)	Getting data on refrigerant gases	To investigate the correlation between university financial issues and CF quantitative evaluation on the basis of university policies and activities

and cost reduction, highlighting the importance of driving the adoption of smart energy campuses. To enable this transition, specific regulations for smart energy integration within HEIs are needed, alongside the necessary infrastructure technologies to support energy efficiency programmes. Creating a unified framework for smart campuses and energy systems, with energy storage playing a pivotal role, is essential for advancing decarbonisation in university buildings. The reduction of CF in global health institutions was examined by Whitfield et al. [92] (**#21**), who found that environmentally sustainable practices align with the core mission of improving global health. Their study offers several recommendations for promoting change, including engaging people through competency-building and collaborative sustainability efforts, amplifying global partnerships, and prioritising specific carbon reduction actions to ensure transparency.

A recent study by Leal Filho et al. [43] assessed the decarbonisation efforts of universities across 40 countries and concluded that HEIs are making progress towards decarbonisation, with renewable energy use becoming increasingly popular and the reduction of carbon emissions seen as a priority. This aligns with the findings of the European Parliament's Committee on Development (DEVE) report, "Achieving the UN Agenda 2030: Overall Actions for the Successful Implementation of the SDGs Before and After the 2030 Deadline" [73], which identifies decarbonisation as a critical component in achieving the SDGs and avoiding serious CC consequences in the coming decades.

Afforestation and reforestation are also key strategies for offsetting CO_2 emissions [4], although their impact may be limited in some contexts. For example, at universities in New Zealand and China, initiatives like tree planting have only yielded partial results compared to other actions, such as reducing overseas travel [20, 100] (**#1**)(**#17**). Cornell University's main campus in the US has implemented a sustainable design for carbon–neutral energy systems, relying primarily on renewable and locally generated energy. This initiative could serve as a model for other campuses and cities with similar characteristics [80] (**#20**). Developing economies also provide examples of successful decarbonisation practices. Jordan University of Science and Technology, despite being located in a semi-arid region, has successfully greened its campus through an action-oriented approach, reducing water usage, CO_2 emissions, and solid waste [1] (**#9**). In Malaysia, 16 HEIs have implemented green practices, producing valuable data and insights for more coherent policymaking at both domestic and global levels [5].

Based on the experiences gathered, Box 1 summarises some of the barriers outlined in the analysed HEIs.

Box 1 Summary of barriers to decarbonisation of HEIs expressed in the selected case studies. Source: authors

- Control of indirect emissions
- Side-effects of energy saving measures (e.g. security, time spent)
- Inappropriate design of buildings, equipment, electrical circuits and other installations
- Lack of emphasis in related themes such as waste management
- Resistance to change behaviours
- Lack of clarity when identifying win–win (finance-emissions) situations
- Insufficient engagement of stakeholders
- Insufficient availability of data for CF
- Lack of priority in budgeting
- Insufficient knowledge on energy consumption profile
- Low cost of business-as-usual solutions when compared to low-carbon new solutions
- Gaps in methods to estimate potential deployment and benefits of low-carbon measures
- Difficulties in retrofitting historic and protected buildings
- Difficulties in methods to locate and estimate sources and sinks
- Difficulties in choosing methods for internal carbon pricing

The case studies show that, despite the variety of approaches and methods used, some common barriers to decarbonisation are seen across the sampled HEIs.

Temporal considerations also have to be considered. Although some of the case studies pre-date recent global shifts such as the COVID-19 pandemic and the acceleration of digital learning, their main conclusions remain applicable. The pandemic, for instance, temporarily altered travel-related emissions but did not fundamentally change the long-term structural challenges, such as energy systems, infrastructure, and governance, identified in earlier studies. Thus, the lessons drawn from these cases continue to offer relevant guidance for current and future decarbonisation strategies.

Considered together, these case studies are not intended to provide in-depth institutional analyses based on primary organisational data, but rather to function as literature-based analytical exemplars. Their value lies in the cross-case synthesis of peer-reviewed evidence documenting decarbonisation practices, barriers, and enabling conditions across diverse higher education contexts. By comparing and aggregating insights reported in the literature, this approach allows the identification of recurring themes and transferable lessons, while remaining consistent with the exploratory scope and mixed-methods design of the study.

Survey

The online survey collected 136 responses from countries worldwide. This section discusses the sample composition and analyses the answers on campus operations.

Respondents

A total of 136 respondents from 39 countries completed the questionnaire with a reasonable number of

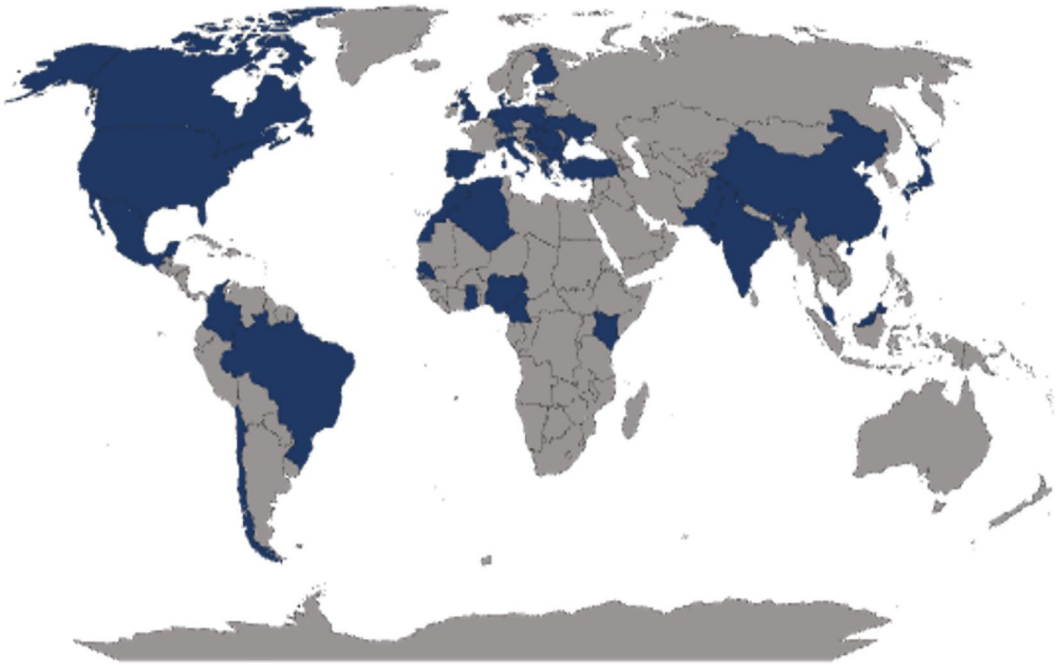

Fig. 5 Distribution of responses per country. Source: authors

representatives from countries in Europe, Africa, North and South America, and Asia (Fig. 5) (Table 5). The sample covers countries with distinct economic and social profiles. Most of the respondents attend public universities (77%) in urban areas (76%) (Table 6).

The distribution of answers on the HEIs characteristics is shown in Table 6. This is to provide the perspective on the breadth and depth of the responses and a reflection of the scale of the institutions. The size distribution of the HEIs that are mentioned in the survey has indicated that most of the respondents attend either large or small universities. 38% of the respondents attend universities with more than 20,000 students and 35% of the respondents attend universities with up to 5,000 enrolled students. About 66% of respondents noted their universities have facilities in multiple locations, possibly reflecting decentralised management systems. Different types of schools within HEIs may require distinct management approaches due to varying nature and environmental considerations. For instance, management in an arts school differs from that in a medical school. Similarly, emission sources vary significantly between different school types. The survey also indicates 81% of respondents attend universities with multiple schools and subjects, highlighting the prevalence of decentralised management.

The distribution of answers on the respondents' characteristics are indicated in Table 7. The study attempted to gain insights into decarbonisation efforts of universities from a multi- stakeholder perspective, however, most respondents are teaching and research staff who are part of the HEI community and shared their experiences for a holistic view.

Operations and practices

Regarding energy use (Fig. 6), a few HEIs produce electricity from renewable energy sources to meet their energy needs. Although the survey demonstrates that only to a limited extent some HEIs are able to generate electricity, the strength of such a strategy to reduce ***Scope 2*** emissions is undeniable. However, the net result of this type of action depends on the profile of the domestic electricity generation system. In countries with a considerable share of fossil fuel-based electricity generation, net emission reductions due to investments in renewable energy are greater than in countries with a considerable share of renewable energy sources. The same variability affects energy efficiency projects. To a moderate extent part of the HEIs supports energy efficiency projects, especially ones related to electricity savings. Efficient lighting technologies stand out as an attractive approach to both reducing energy consumption and GHG emissions. To a lesser extent, HEIs adopt policies and incentives to reduce energy consumption for heating and cooling in buildings.

Commuting is also relevant in terms of GHG emissions. In comparison to energy demand, emissions from commuting are usually reported as ***Scope 3*** emissions.

Table 5 Respondent distribution by country. Source: authors

Country	Number of responses	Country	Number of responses
Romania	19	Mexico	2
United States of America	13	Pakistan	2
Canada	11	Algeria	1
China	9	Bhutan	1
Spain	9	Bulgaria	1
Italy	8	Cameroon	1
United Kingdom	7	Colombia	1
Brazil	5	Denmark	1
Poland	5	Greece	1
Portugal	4	Hungary	1
Bosnia and Herzegovina	3	Kenya	1
Chile	3	Morocco	1
Ghana	3	Senegal	1
Latvia	3	Serbia	1
Nigeria	3	Slovakia	1
Finland	2	Taiwan	1
Germany	2	The Netherlands	1
India	2	Turkey	1
Japan	2	Ukraine	1
Malaysia	2		

The attention devoted by HEIs to such types of emissions is lower than the efforts targeting energy efficiency and generation of electricity from renewable energy sources (Fig. 7). To a limited extent, HEIs have sustainable policies that affect staff travel plans as part of their GHG emission reduction strategies. Promotion of sustainable mobility initiatives for staff, students or the general public are also part of the limited extent strategies targeting GHG emission reductions that have been identified by respondents. Measurements by Sangwan et al. [72] and Adeyeye et al.[2] confirm that HEIs' CF is composed to a great extent by commuting emissions.

The respondents highlighted the use of refrigeration gases that minimise the contribution to greenhouse effect (Fig. 8). This is interesting and could lead to the need to understand potential bias or group differences. Many countries adhered to the Kigalli amendment to the Montreal Protocol recently, and reduction goals should lead to eliminating 80% of hydrofluorocarbon (HFC) gases by 2040. It is not expected that gases such as R134a and R410a are currently extensively phased out. Regarding energy consumption of refrigeration systems, Yasuoka et al. [96] bring the use of IOT to cut energy consumption. None of the literature case studies brought an example of action in this direction. The second ranked action was on lightning. However, Bulunga and Thondhlana [13] brought the concerns of users with security hazards when switching lights off, which caused resistance to expected behaviour. On the other hand, examples of alternative sources of energy such as application of PV systems [65]. Horan et al. [31] cite an example of implementation of PV and micro-wind turbines power generation. Campos-Guzmán et al. [14] recommend that when PV projects cannot be started at once, a staged implementation must be put in place.

Waste handling, disposal, recycling, is one of the main concerns in the survey, and food waste seems to be one of the main issues (Fig. 9). Handling of waste is brought up as an important ***Scope 3*** emission category by several authors, such as Vrachni et al. [90] and Kiehle et al. [38]. Food waste seems to be a special concern. Rojas-Vargas et al. [70] say that there is a general lack of interest in this source, and this is why it is still the reason for action. Figure 10 shows the responses of the respondents regarding saving energy, managing chemical waste and reducing carbon emissions in the laboratories.

Barriers to decarbonisation

Figure 11 shows the answer regarding the barriers to decarbonisation. It is important to note that the main barriers are managerial, such as limited budget, lack of managerial support, lack of qualification staff and lack of routines and procedures to get data on emission sources. The only technical issue ranked among the most important ones is the existence of old buildings, which might be more difficult to retrofit. Historical and listed buildings are a challenge when it comes to decarbonisation in HEIs. Other technical barriers such as lack of renewable alternatives and campus site complexity are poorly ranked. Regarding lack of financial resources, Abu Qdais et al. [1] remark the importance of finding win–win situations to make it easier to justify investments. Maistry and McKay [54] recommend the assignment of an energy-champion at the highest level of the organisation to assure management is involved.

The main barrier is budget constriction. A similar barrier is described by Whitfield et al. [92] and Palanichamy and Goh [65]. Whitfield et al. [92] also quoted poor energy efficiency of historic and protected buildings as one out of the barriers. It is interesting that lack of policies and support by top management is not quoted in the case studies. Limited staff commitment shows up in another form: resistance to change, reported by Vásquez et al. [91] and Whitfield et al. [92]. Lack of knowledge was an issue found by Maistry and McKay [54], and lack of monitoring routines seem to be the expression of similar findings by Maistry and Annegarn [53] and Barron et al. [8].

Stationary consumption and purchased electricity are graded as main opportunities for emissions reduction.

Table 6 Information on the size and attributes of HEIs (n = 136). Source: authors

Category	Answers	*n*	Frequency (%)
HEIs' size	More than 20,000 students	51	38
	Up to 20,000 students	16	12
	Up to 10,000 students	21	15
	Up to 5,000 students	48	35
Description of the HEIs from a campus perspective	Multi-campus (more than one geographical location, separated by a distance so that campus administrators are at least partially independent)	90	66
	Single campus (only one geographical location, under general administration, even if a number of courses are performed)	46	34
HEIs description in terms of locality	Rural	5	4
	Suburban	28	21
	Urban	103	76
HEIs' type	Private Higher Education Institution	31	23
	Public Higher Education Institution	105	77
HEIs' focus	Universal (it covers all subjects, including engineering and medicine);	56	41
	General (it covers most subjects, but not all of them);	54	40
	Specific (ex. technical universities, university of applied sciences, liberal arts college, etc.);	23	17
	Focuses on mid-career education for professionals	1	1
	Liberal arts undergrad, known for medical and law schools	1	1
	Social sciences	1	1

They seem to be related to heating in predominantly cold places and air conditioning (refrigeration) in warmer weather. Stationary consumption seems to be a priority in several institutions (Fig. 12). However, there seems to be a gap regarding refrigeration systems. Valls-Val and Bovea [87] show that less than 40% of GHG inventories at universities included emissions from refrigeration systems. Mobility apps usually do not bring the real fuel and precise distances, making it difficult to measure. Improvement methods would include electric vehicles and use of biofuels. Commuting and business travels are also ranked as important opportunities. However, ***Scope 3*** emissions are known to be challenging to measure [39, 75].

Appropriate commuting measurement would involve getting information on routes, mileage and transport modes (even if more than one mode) for each individual trip. This seems to be not feasible. So, sampling and simplified methods have to be used, and the validation is still a challenge. Kiehle et al. [38], Pacca et al. [64] and Veludo et al. [89] are some of the authors pointing this issue. In the case of business travels, air tickets can come from different pockets—HEIs budget, projects budget, partnering, which makes it difficult to gather information precisely, although estimation for each travel is relatively simple. When dealing with car business travel, the use of taxi and vehicle features introduce imprecision in

Table 7 Position of respondents and gender (n = 136). Source: authors

Position/Gender	Description	*n*	Frequency (%)
Respondent's position at HEIs	Teaching staff and researcher	73	54
	Student (Bachelor, Master, PhD, etc.)	21	15
	Teaching staff	18	13
	Researcher	14	10
	Administrative staff	7	5
	Campus services staff (Infrastructure or campus operation)	2	1
	Member of the Faculty (not staff)	1	1
Gender	Female	69	51
	Male	63	46
	Non-Binary	2	1
	Prefer not to say	2	1

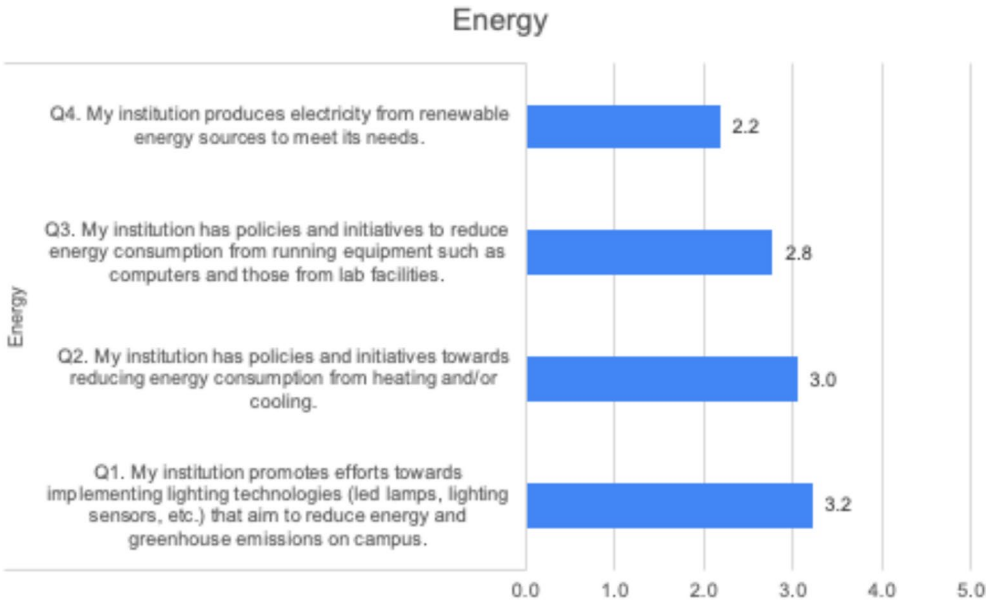

Fig. 6 Barriers to decarbonisation—Energy. Source: authors. *I do not know* (Q1): 9 respondents; *I do not know* (Q2): 9 respondents; *I do not know* (Q3): 16 respondents; *I do not know* (Q4): 18 respondents

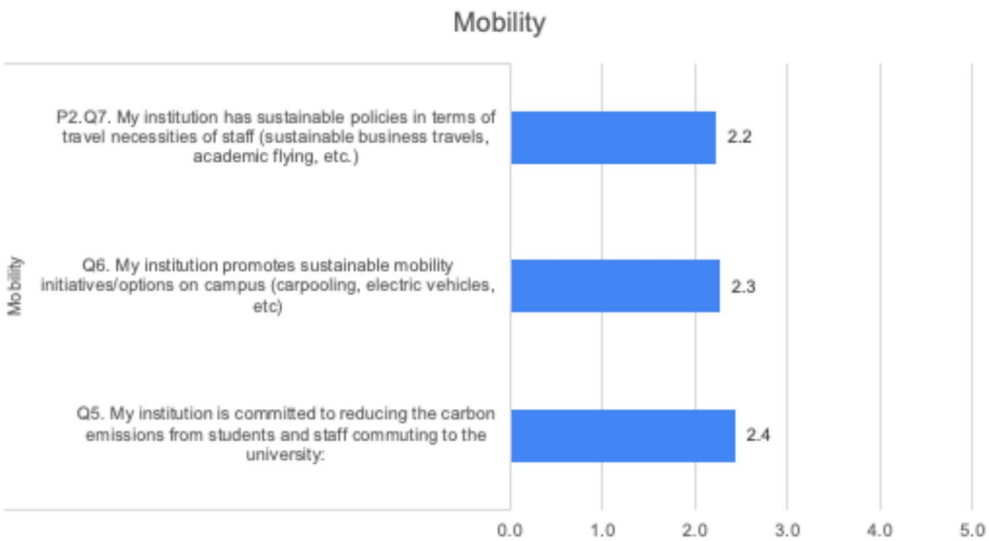

Fig. 7 Barriers to decarbonisation—Mobility. Source: authors. *I do not know* (Q5): 5 respondents; *I do not know* (Q6): 5 respondents; *I do not know* (Q7): 15 respondents

the estimation methods, particularly in countries where a variety of fuels are used.

Taken together, the survey results portray a consistent pattern of barriers and opportunities for decarbonisation within HEIs. Respondents across regions identified limited financial resources, weak managerial support, and insufficient staff training as the main obstacles to implementing effective emission-reduction measures. Technical barriers, such as ageing infrastructure and the lack of renewable alternatives, were considered secondary to organisational and cultural challenges. The results also show that although energy and mobility remain the dominant emission sources, systematic data collection and performance monitoring are often lacking, constraining evidence-based decision-making. Overall, the findings emphasise that successful decarbonisation depends as much on institutional commitment and governance mechanisms as on technological innovation. This

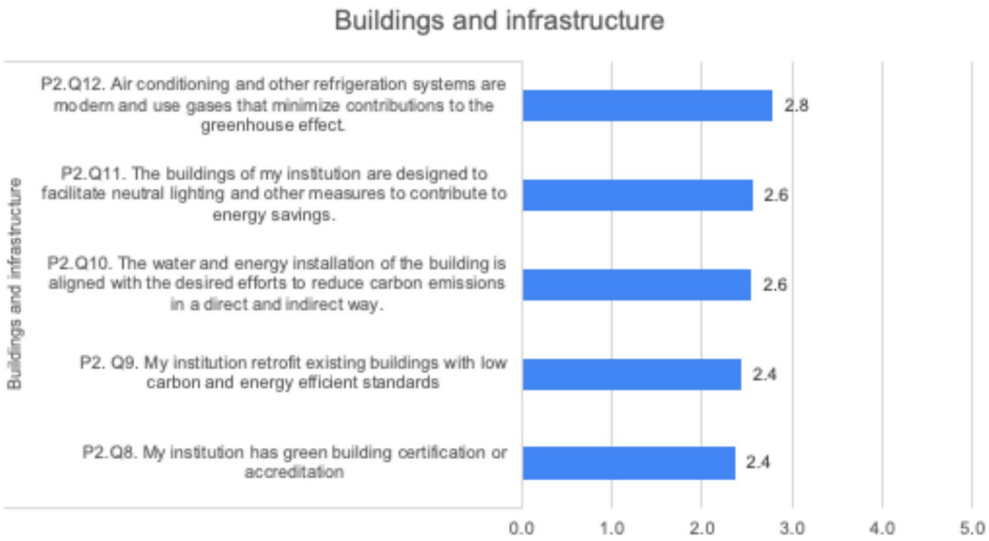

Fig. 8 Operations and practices—Buildings and Infrastructure. Source: authors. *I do not know* (Q8): 35 respondents; *I do not know* (Q9): 27 respondents; *I do not know* (Q10): 22 respondents; *I do not know* (Q11): 17 respondents; *I do not know* (Q12): 27 respondents

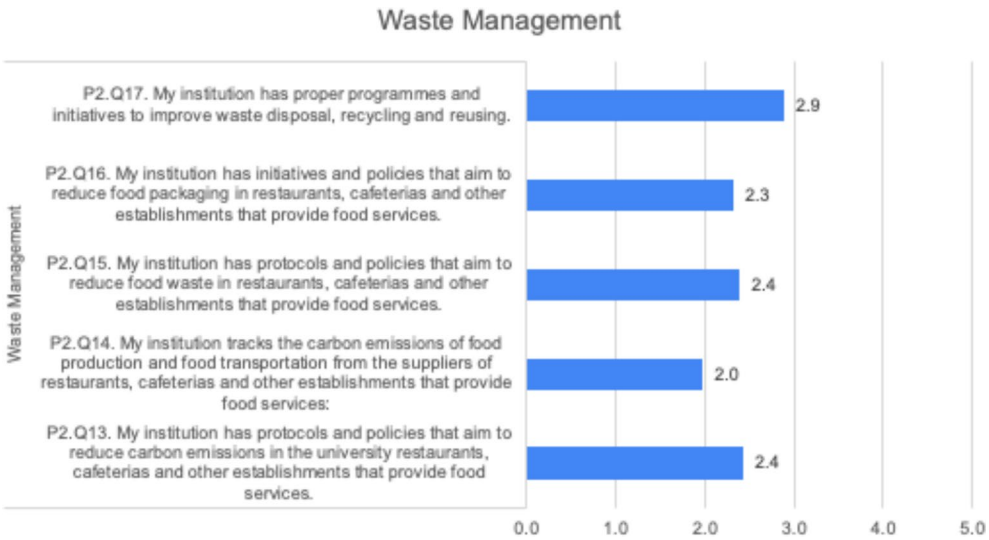

Fig. 9 Operations and practices—Waste Management. Source: authors. *I do not know* (Q13): 27 respondents; *I do not know* (Q14): 34 respondents; *I do not know* (Q15): 29 respondents; *I do not know* (Q16): 28 respondents; *I do not know* (Q17): 19 respondents

understanding provides the foundation for the following section, which explores ways in which these barriers can be addressed.

Overcoming structural and contextual barriers to decarbonisation in HEIs

Whereas raising awareness and building knowledge are foundational to decarbonisation in HEIs, these efforts must be complemented by addressing deeper structural, cultural, and political barriers. A holistic institutional shift requires more than education—it demands action in various areas. For example:

Standardising Carbon Accounting Practices. In line with the findings from the literature review, the study recommends that universities adopt harmonised and transparent approaches to carbon accounting. Existing standards such as the GHG Protocol [27] , ISO 14064-1 [32], and PAS 2060 [10] provide valuable guidance, but their application in HEIs remains inconsistent. Establishing a common framework specifically tailored for HEIs would enable greater comparability of emissions data

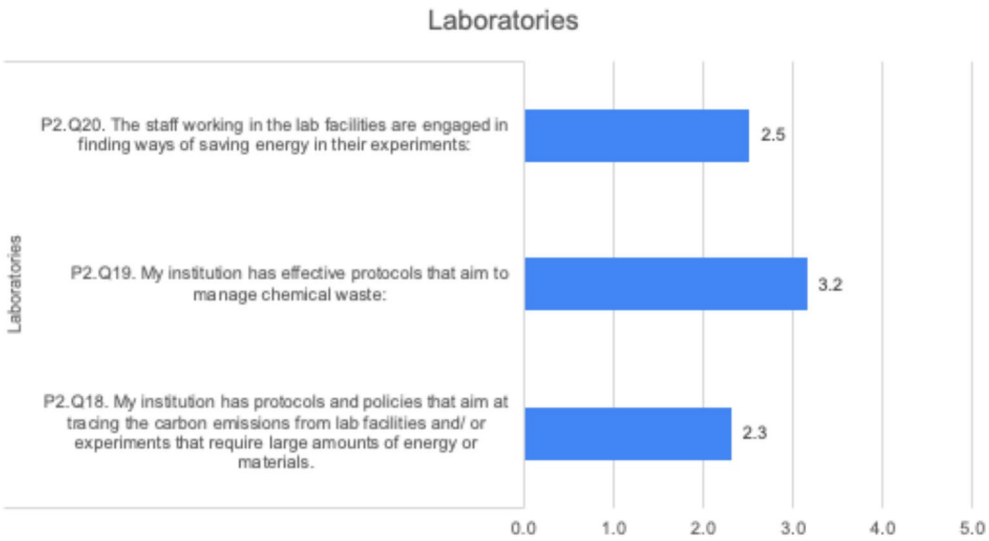

Fig. 10 Operations and practices—Laboratories. Source: authors. *I do not know* (Q18): 50 respondents; *I do not know* (Q19): 45 respondents; *I do not know* (Q20): 44 respondents

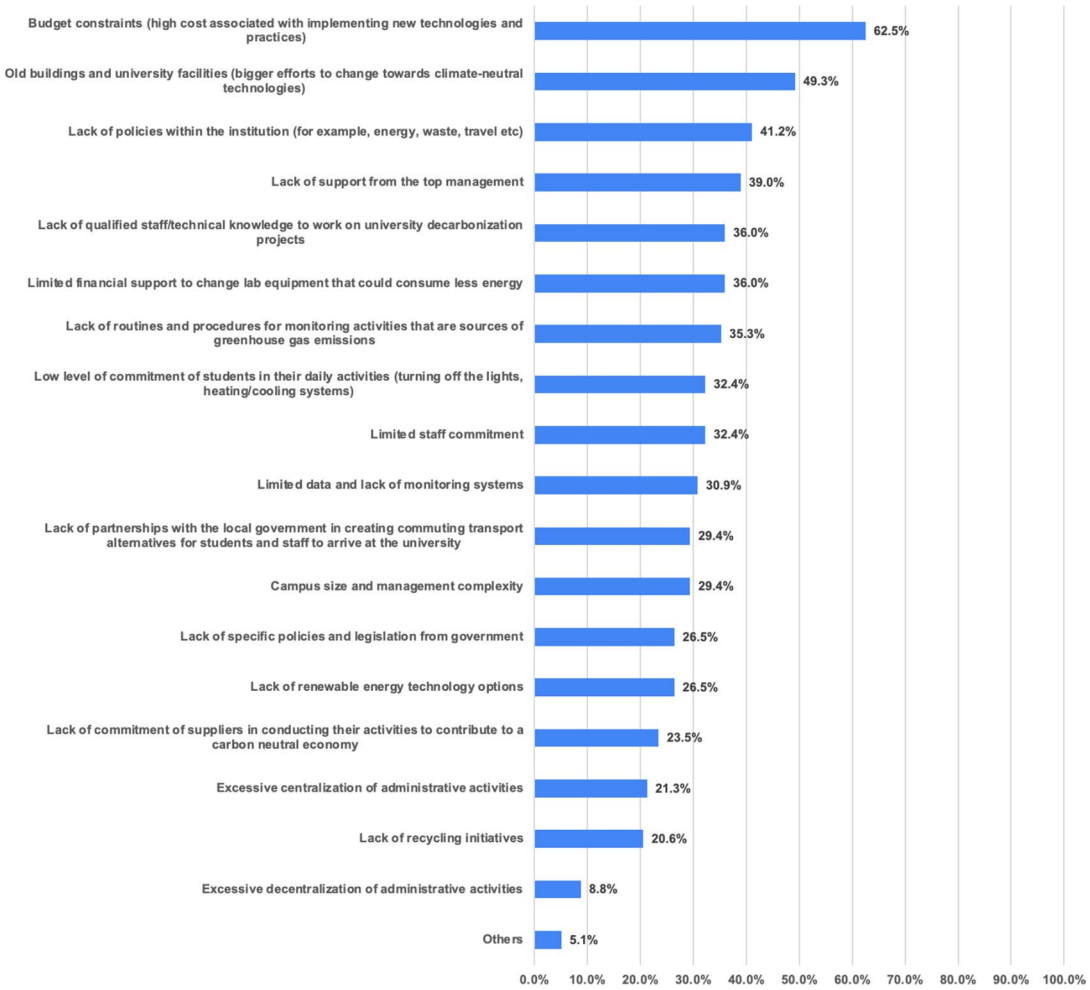

Fig. 11 Frequency of perceived challenges and barriers to campus decarbonisation (n = 136). Source: authors

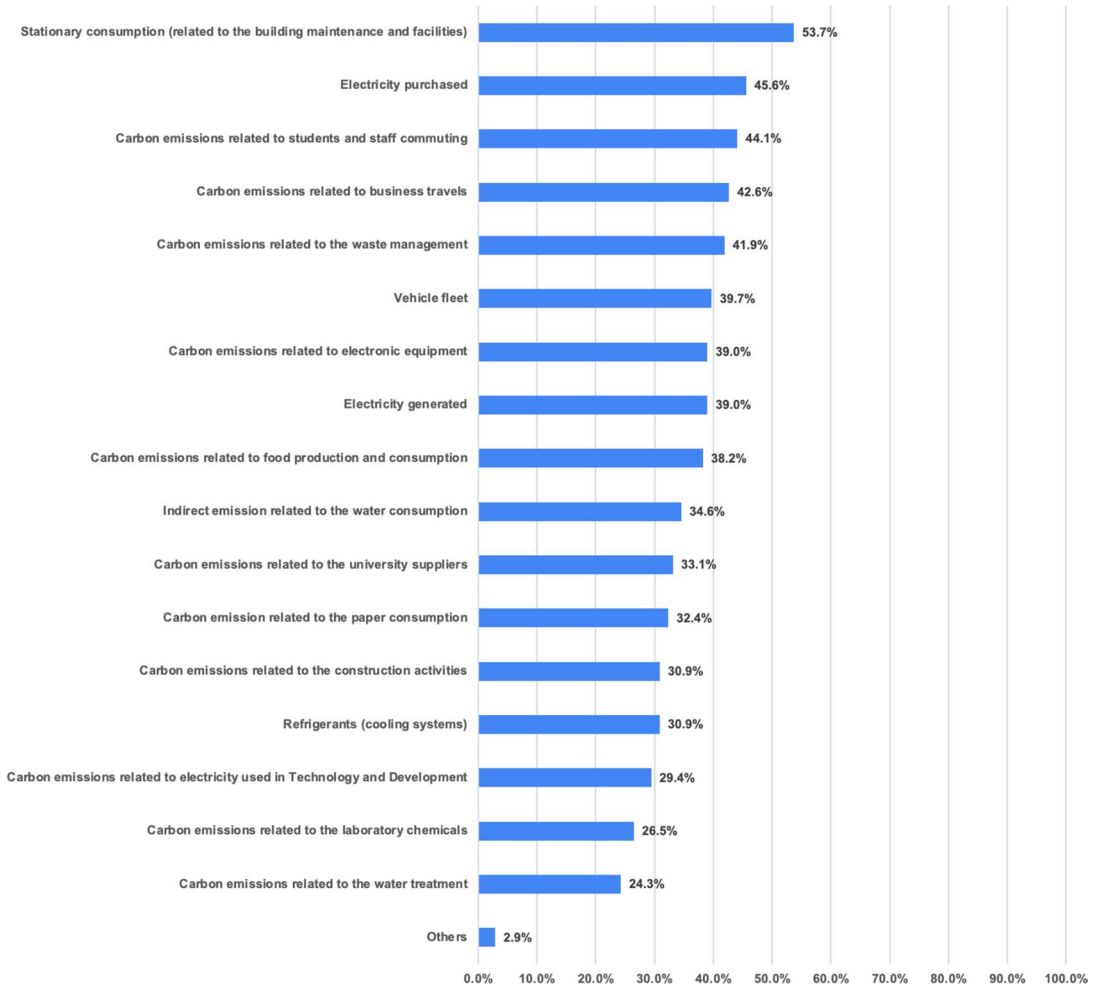

Fig. 12 Perceived opportunities for reduction of carbon emissions in the respondent's HEIs (n = 136). Source: authors

across institutions and countries, improve benchmarking, and support more coherent monitoring of progress towards carbon–neutral operations. Developing and sharing open-access tools based on such standards would further strengthen transparency and encourage institutional collaboration in decarbonisation efforts.

The Need for Cultural and Political Considerations. HEIs operate within diverse cultural and political contexts, especially those with multiple campuses across regions or countries. Cultural differences can influence attitudes toward sustainability, necessitating tailored approaches to climate action [9]. Politically, both external support and internal governance structures play crucial roles. Mazhar et al. [55] identified governance and management as a critical success factor for successfully embedding carbon management that are pertinent not just for the higher education sector, but to organisations broadly. Public and municipal engagement is key to the legitimacy and feasibility of decarbonisation projects [26, 100]. Internally, transition teams should be empowered with decision-making authority, free from bureaucratic constraints, to drive meaningful change [26].

The Need to Acknowledge Institutional Structures and Operational Constraints. The effectiveness of climate action within HEIs is also shaped by their organisational architecture. Several studies highlight the difficulties in accessing accurate data on carbon emissions, especially regarding refrigerants and indirect emissions, which hampers the creation of comprehensive carbon inventories [9]. Staff engagement is equally critical—personnel can either enable or obstruct sustainability efforts depending on institutional incentives and training opportunities [54]. Appointing energy champions at senior levels can help embed sustainability within university governance.

The Need to Pursue Technical Pathways and Strategic Planning. Implementing decarbonisation technologies in a resource-constrained environment requires

careful planning. Palanichamy and Goh [65] proposed a phased approach to installing PV systems, while Campos-Guzmán et al. [14] used the AHP to prioritise interventions based on feasibility and impact. Timmons and Weil [81] argue that institutions should pursue a combination of renewable energy generation, electrification of end uses, and energy efficiency—focusing on achieving carbon neutrality at the lowest cost, rather than prioritising immediate financial returns.

The Need for Institutional and Student Engagement. Behavioural change is another lever for emissions reduction. Stakeholders including staff and students and leadership engagement are key factors for carbon reduction in universities [55]. Franco et al. [25] found that students' energy-saving attitudes are shaped by their perceptions of the roles of citizens, scientists, and governments. Their study identified distinct behaviour patterns, such as eco-friendly consumption and conservation efforts, demonstrating the need for stakeholder collaboration to embed decarbonisation into campus life.

The Need to Acknowledge Carbon Lock-in and Long-Term Risk. One of the most persistent challenges is carbon lock-in, the continued reliance on fossil fuel infrastructure despite sustainability goals [94]. Addressing this risk requires long-term planning that anticipates the eventual decommissioning of high-emission systems and embraces low-carbon alternatives at scale.

The Need for Innovative Practices and Institutional Learning. Several HEIs are pioneering methods to overcome decarbonisation barriers. In Ireland, Horan et al. [31] developed a model to assess the carbon-saving potential of decarbonisation technologies, using spatial data from rooftops and parking areas. In the US, ICP is gaining traction as a mechanism to incentivise low-carbon decisions and promote transparency [8]. Similarly, the concept of "smart campuses" incorporating ICT and decentralised energy systems, is proving essential to modern energy strategies in HEIs [40].

The Need to Combine Global and Local Learning. Notable case studies from both developed and developing economies illustrate how different contexts adapt to shared goals. Cornell University, US, has implemented a carbon–neutral energy system that serves as a blueprint for others [80]. In more resource-constrained settings, Jordan University of Science and Technology has achieved sustainability gains in a semi-arid environment [1], while Malaysian universities have adopted a variety of green practices across 16 institutions [5]. Yet, some well-intentioned actions, such as afforestation and reforestation, have shown limited impact when compared to systemic interventions. De Villiers et al. [20] and Zheng et al. [100] found that despite green surroundings, campuses in New Zealand and China remained unsustainable due to high energy and travel emissions. These examples underscore that effective pathways are highly context-dependent shaped by geographical, socio-economic, and institutional conditions.

The Need for Specific Strategies. Internationally, decarbonisation is increasingly embedded in sustainability frameworks. DEVE identified decarbonisation as one of the six priority areas to meet the SDGs by 2030, emphasising the need for equitable and sustainable energy infrastructures [73]. Leal Filho et al. [43] reaffirm that many universities are already progressing, particularly through increased use of renewable energy and emissions reduction strategies.

As discussed above, advancing decarbonisation in higher education requires more than isolated or technology-driven efforts such as addressing institutional inefficiencies, promoting leadership that bridges academic and operational domains, and aligning cultural and political realities with technical capacity. As the examples from diverse regions show, effective strategies are inherently context-dependent so the strengthening of international cooperation and knowledge exchange can accelerate collective learning and support more equitable climate action across the HEIs so that they can act as catalysts for transformative climate leadership within the sector and beyond.

Conclusions

Based on the empirical evidence from a worldwide survey of 136 respondents across 39 countries, and also from the thematic analysis of over 20 literature-based case studies, this study underpins several important conclusions fitting the goal of mapping operational decarbonisation strategies, constraints and institutional practices in HEIs. The analysis shows that most of the surveyed institutions are committed to carbon neutrality or to deep emission reductions focusing on ***Scope 1*** and ***2*** emissions. This is demonstrably reflected in the data by widespread reporting of certain actions adopted. As described in the responses given to the enquiry on energy system, a large number of institutions are turning to renewable sources, with "on-site generation"—especially solar PV—the most used strategy among survey responses and studies. Concurrently, the information on campus operations indicates that ongoing energy-efficiency efforts are nearly universal, reflected in reported actions—such as retrofitting the buildings and integrating building management systems and LED lighting replacements—that respondents correlate directly with the reduced emissions. However, the study also notes that there are identifiable institutional structures and obstacles to it, which in turn determine the way things are actually moving forward.

The data on governance and delivery revealed that, in general, financial constraints, regulatory barriers, and ageing infrastructure are the most common obstacles across all regions. Internal organizational challenges are also likely to reinforce these barriers, including siloed decision-making and budgeting, as described by several administrative and academic respondents. In synthesising the insights on enabling factors, the analysis suggests that successful initiatives in this study explicitly correlate in the data to two specific institutional practices: First, the active involvement of stakeholders—students, faculty, and staff—through dedicated programmes and governance committees that survey respondents find associated with increased uptake of sustainability initiatives and a more robust institutional culture of accountability. Second, the establishment of formal monitoring and reporting frameworks for carbon emissions, which the case studies have identified as an essential component for strategy evaluation, target setting, and institutional accountability.

This study has some limitations. While geographically diverse, the survey sample is not representative statistically of all HEIs around the world, and the underrepresentation of operational staff perspectives could limit the granularity of implementation data. Also, case studies grounded in literature offer thematic depth and comparability across contexts but lack primary organisational-level analysis. Moreover, the cross-sectional design measures only one point in time and does not document longitudinal change. Nevertheless, the triangulation of survey data and published case studies provides rich indicative information on common paths and barriers. Finally, the evidence-based results support that decarbonisation of HEIs in terms of operations is a multifaceted process, taking shape by commitments made in tangible steps and manifested in actions in energy procurement, resource use, performance, and governance.

The results highlight the fact that the effectiveness of decarbonisation measures is dependent on breaking down chronic structural and financial factors in the implementation, and is substantially supported by institutional practices that promote the engagement of all stakeholders and an open, transparent measurement of its impact. By analysing these strategies and constraints, the study provides a timely an insight into how universities are mobilising operational and institutional resources to reduce their climate impact.

Overall, decarbonisation remains a complex and evolving process. It requires continuous commitment, flexibility in the face of new challenges, and the capacity to adapt to technological advancements and shifting sustainability paradigms. A long-term, strategic vision, embedded within the university's core mission, strategy and institutional planning, is essential for sustained progress and net zero carbon future.

Abbreviations

AHP	Analytical hierarchy process
ASU	Arizona State University
BSI	British Standards Institution
CC	Climate change
CF	Carbon footprint
DEVE	European Parliament Committee on Development
DTU	Denmark Technical University
EEIO	Environmentally extended input–output
EIO-LCA	Economic input–outputlife cycle assessment
GHG	Greenhouse gas
GIA	Gross internal area
GPS	Global positioning system
HEC	Higher Education Campus
HEI	Higher Education Institution
HFC	Hydrofluorocarbon
ICT	Information and Communication Technologies
ICP	Internal carbon pricing
IoT	Internet of things
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
NUS	National University of Singapore
PAS	Publicly Available Specification (standards, e.g. PAS 2050, PAS 2060)
PV	Photovoltaic
UC	University of California
UK	United Kingdom
UN	United Nations
US	United States
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute

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Author contributions

WLF: conceptualization, methodology, writing—original draft, writing—review and supervision. IE: paper management, editing and submission, writing—review, support with data collection and processing. AOE: support with data collection and processing. MME: support with data collection and processing. FMSA: support with data collection and processing. MAPD: support with data collection and processing, writing—review. JHE: support with data collection and processing. MM: support with data collection and processing. JM: support with data collection and processing. AG: support with data collection and processing, writing—original draft, writing—review. AK: paper management and submission. YAA: paper management and submission, writing—review. MV: support with data collection and processing. All authors reviewed the manuscript.

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Data availability

The datasets analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Informed consent was obtained from all individual participants included in the study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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