

1 Decarbonising University Operations: Strategies and Challenges for 2 Higher Education Institutions

3 Walter Leal Filho^{1,2,3}, Alexandre de Oliveira e Aguiar⁴, Muhammad Manzoor Elahi⁵, Fardous
4 Mohammad Safiul Azam⁶, Maria Alzira Pimenta Dinis^{7,8}, João Henrique Paulino Pires Eustachio⁹,
5 Muhammad Mazhar¹⁰, Janaina Mazutti¹¹, Andrea Gatto^{12,13,14}, Iker Etxano^{15,*}, Aristeia Kounani¹⁶,
6 Yusuf A. Aina¹⁷, Maria Viota¹⁸

7 1. Department of Natural Sciences, Manchester Metropolitan University, Chester Street,
8 Manchester, UK. Email: w.leal@mmu.ac.uk; ORCID: 0000-0002-1241-5225.

9 2. Merito University, Poland.

10 3. Hamburg University of Applied Sciences, Faculty of Life Sciences, Germany.

11 4. University of São Paulo, School of Sciences, Arts and Humanities. Rua Arlindo Béttio, 1000 -
12 Ermelino Matarazzo, São Paulo - SP, Brazil, CEP 03828-000. Email: aoaguiar@usp.br; ORCID:
13 0000-0003-3413-064X

14 5. Department of Political Science, Government College University Lahore, Pakistan. IRSIP
15 Research Fellow, School of Social Sciences, University of Manchester, UK. Email:
16 mmelahi@gcu.edu.pk; ORCID: 0000-0002-5279-1807

17 6. College of Life Science, Neijiang Normal University, No. 1, Hongqiao Street, Neijiang, Sichuan
18 Province, 641100, PR China. Email: shojibbiotech@yahoo.com; ORCID: 0000-0002-9337-273X

19 7. Fernando Pessoa Research, Innovation and Development Institute (FP-I3ID), University
20 Fernando Pessoa (UFP), Praça 9 de Abril 349, 4249-004 Porto, Portugal. Email:
21 madinis@ufp.edu.pt; ORCID: 0000-0002-2198-6740

22 8. Marine and Environmental Sciences Centre (MARE), University of Coimbra, Edifício do
23 Patronato, Rua da Matemática, 49, 3004-517 Coimbra, Portugal.

24 9. Hamburg University of Applied Sciences, Faculty of Life Sciences, Research and Transfer Centre
25 Sustainability & Climate Change Management (FTZ-NK), Ulmenliet 20, 21033 Hamburg, Germany.
26 Email: jh.eustachio@gmail.com; ORCID: 0000-0002-6782-3904

27 10. Department of Management, Nottingham Business School, Nottingham Trent University, 50
28 Shakespeare Street, Nottingham, NG1 4FQ, UK. Email: muhammadusman.mazhar@ntu.ac.uk

29 11. Graduate Program in Civil and Environmental Engineering, University of Passo Fundo,
30 Campus I, Passo Fundo, Brazil & Hamburg University of Applied Sciences, Faculty of Life Sciences,
31 Germany. E-mail: janainamazutti@gmail.com; ORCID: 0000-0002-1929-4155.

32 12. College of Business and Public Management, Wenzhou-Kean University, Wenzhou, China.
33 Email: agatto@kean.edu; ORCID: 0000-0003-1005-3571

34 13. Centre for Studies on European Economy, Azerbaijan State University of Economics,
35 Azerbaijan.

- 36 14. Division of International Studies, College of International Studies, Korea University. 145
37 Anam-ro, Seongbuk-gu, Seoul 02841, Republic of Korea.
- 38 15. Department of Applied Economics, Ekopol, Hegoa. University of the Basque Country
39 (UPV/EHU). Faculty of Social and Communication Sciences, 48940 Leioa (Bizkaia), Basque
40 Country (Spain). Email: iker.etxano@ehu.eus; ORCID: 0000-0003-1782-464X
- 41 16. Department of Agriculture, Program of Agricultural Economics & Entrepreneurship,
42 International Hellenic University, Thessaloniki, Greece. Email: akounani@yahoo.gr; ORCID: 0000-
43 0002-9976-4291
- 44 17. Department of Geomatics Engineering Technology, Yanbu Industrial College, Yanbu, Saudi
45 Arabia. Email: yaina@rcjy.edu.sa; ORCID: 0000-0002-0763-9865
- 46 18. UNESCO Chair on Sustainable Development and Environmental Education. University of the
47 Basque Country (UPV/EHU). Basque Country (Spain). Email: viota.maria@gmail.com
- 48 (*) Corresponding author: Iker Etxano (iker.etxano@ehu.eus)

49 **Abstract**

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

58 **Results:** The findings underscore awareness initiatives that enhance understanding of
59 decarbonisation among educators and students in universities, and communities. The case
60 studies as a review of experiences from diverse geographical regions illustrate varying strategies
61 for carbon emissions reduction in HEIs, underscoring the adaptability of decarbonisation efforts
62 across contexts. Additionally, cultural and political factors emerge as key determinants, requiring
63 tailored strategies to navigate diverse contexts and garner public support. Finally, institutional
64 structures, including data availability and personnel engagement, are identified as key enablers
65 or barriers to effective decarbonisation efforts.

66 **Conclusions:** The novelty of the paper resides on the fact that it highlights the need for
67 integrating decarbonisation goals into institutional governance and planning mechanisms is
68 essential for achieving long-term goal of net zero carbon and aligning with the global UN
69 Sustainable Development Goals (SDGs). The study advocates for a holistic approach that
70 considers social, economic, and environmental dimensions in advancing decarbonisation within
71 HEIs. By addressing barriers, HEIs can pave the way for a sustainable and low carbon future while
72 serving as catalysts for broader societal change.

73

74 **Keywords**

75 Higher Education Institutions (HEIs), climate change (CC), decarbonisation, carbon emissions
76 reduction, sustainability, sustainable campus.

77 **Introduction: The contribution of universities to climate change**

78 Universities can play a key role in the fight against climate change (CC), particularly through the
79 decarbonisation of their own operations. While universities contribute to climate action through
80 education, research, and innovation, their campuses also function as complex organisations with
81 substantial environmental footprints (Bueno et al., 2021). Reducing energy consumption,
82 decarbonising transport systems, and applying circular economy principles to manage waste and
83 resources are therefore central operational challenges (Stein, 2023). By addressing these
84 dimensions, universities can lower their carbon footprint (CF) and demonstrate leadership
85 through practice. Although research and teaching activities contribute to awareness-raising and
86 the development of new approaches to climate mitigation (Agboola and Emmanuel, 2016;
87 McCowan, 2020;; Monteiro et al., 2023), this study focuses specifically on operational
88 decarbonisation, examining how institutional practices, structures, and constraints shape
89 universities' ability to reduce emissions. To reduce carbon emissions, universities can invest in
90 renewable energy, enhance energy efficiency, and minimise waste (Kalkan et al., 2011).
91 Sustainable practices include green procurement, the use of sustainable building materials, and
92 the promotion of eco-friendly transportation options (Kasai and Jabbour, 2014; Fissi et al., 2021).
93 These efforts may also involve divesting from fossil fuels, reducing waste, and establishing
94 sustainable campus gardens (Ellison et al., 2019; Quigley et al., 2020; Torrijos et al., 2021).

95 Sustainable practices in Higher Education Institutions (HEIs) have significant societal impacts
96 (Worsham and Brecha, 2017; Horan et al., 2019), as the role of HEIs has shifted from traditional
97 centres of learning to emerging models of sustainable, resilient, and practical governance capable
98 of addressing complex modern challenges (Leal Filho et al., 2021). These models center upon
99 long-term ecological and social health (sustainability), the capacity to absorb shocks and adapt to
100 crises (resilience), and practical and effective implementation (practicality). They are typically
101 more collaborative, participatory, and evidence-based strategies than the classic top-down
102 approaches. This entails an integration of diverse stakeholders, data-driven policies, and an

103 ability to be flexible so that institutions can weather disruptions, like CC or pandemics, but are
104 also intentional about stewarding resources and equity for future generations. Consequently,
105 decarbonisation efforts in HEIs encompass multiple domains, including governance and
106 leadership, extending beyond individual engagement. In light of hesitant policy responses from
107 governments, climate leadership by other institutions is vital for maintaining momentum,
108 fostering innovation, and supporting informed climate decisions at a broader scale (Barron et al.,
109 2020). Additionally, universities are uniquely positioned to educate students and the wider public
110 about CC and its impacts. Through the provision of courses, research, and degree programmes
111 focused on CC and sustainability, universities contribute to raising awareness and fostering a
112 broader culture of sustainability (Mokski et al., 2023). They also play an important role in training
113 graduates for emerging green and climate-related sectors and may influence policy through their
114 research activities (Ma et al., 2023). However, while these educational and research functions are
115 central to universities' societal missions, the present study does not examine curricular,
116 pedagogical, or policy impacts directly. Instead, it concentrates on operational decarbonisation,
117 analysing how institutional practices and constraints shape universities' ability to reduce
118 emissions in their day-to-day operations.

119 Through the study of the impacts of CC and proposing solutions, universities can inform
120 governments, businesses, and other organisations on effective decarbonisation strategies
121 (Locatelli et al., 2017; Ma et al., 2023). Leading universities across the globe have adopted net-
122 zero strategies to become carbon-neutral HEIs (Udas et al., 2018). These strategies include
123 reducing their CF and engaging in carbon offsetting. Greenhouse gas (GHG) emissions metrics are
124 gaining importance in terms of consistency and comparability (Helmets et al., 2021; McCowan,
125 2022), although the allocation of emissions follows a straightforward scheme: **Scope 1**
126 encompasses direct university activities; **Scope 2** includes purchased energy; and **Scope 3** covers
127 upstream activities such as transportation and investments.

128 Universities are decarbonising their core business operations and there are various case study
129 examples around the world. Successful examples of universities that have committed to reducing
130 carbon emissions and pledged to become zero-carbon include Arizona State University (ASU).
131 ASU has reduced its **Scope 3** emissions by 49 % since 2007, and achieved carbon neutrality for
132 **Scope 1** and **Scope 2** emissions in 2019 through measures such as improving energy efficiency,
133 adopting sustainable building practices, purchasing carbon offsets, and expanding the use of
134 renewable energy. ASU promotes sustainable transportation options and sustainable purchasing
135 policies through specific initiatives (ASU Sustainability – Climate Positive, 2019). Similarly, the
136 University of California's (UC) commitment to becoming carbon neutral builds on its long-
137 standing leadership in sustainable practices and climate research. Initially, the net-zero target
138 was aimed to be achieved by 2025 (UC Carbon Neutrality Initiative, 2013); later, the UC
139 administration reset it to 2045 to 'fully decarbonise' university operations. UC's efforts to
140 improve energy efficiency, develop renewable energy sources, and enact strategies to cut carbon
141 emissions are supported by the Global Climate Leadership Council and funding for student-
142 generated projects (UC's Sustainable Practices Policy, 2023). The University of Cambridge's
143 'Cambridge Zero 2019' aims to harness the University's research capabilities to respond to CC
144 and transition to a resilient and sustainable future. The initiative focuses on developing greener
145 technologies and materials and addressing every aspect of a zero-carbon future, equipping
146 leaders with the necessary skills (Cambridge Zero Carbon, 2019).

147 The University of Edinburgh's 'Climate Strategy: Zero by 2040' aims to reduce carbon emissions
148 by 26,838 tCO₂e by 2025 through sustainable travel policies and low-carbon technology
149 investments. The University has already invested over £30m in low-carbon technology and
150 attracted more than £50m in climate research since 2010 (The University of Edinburgh, 2016).
151 Denmark Technical University (DTU) applies the 'Living Lab' concept on its campuses to develop
152 sustainable solutions in new builds, energy supply, and waste sorting (Denmark Technical
153 University, 2018). By 2021, DTU had expanded indoor waste sorting into 12 fractions and
154 established a digital recycling exchange. The University prioritises using more wood in building

155 projects and has switched to heating supply from waste management, halving carbon emissions
156 (DTU's Sustainability Policy, 2020–2025).

157 Lund University's analysis of its climate impact showed that emissions dropped by approximately
158 25% between 2018 and 2020 although part of this reduction was probably due to mobility
159 restrictions during the COVID-19 pandemic (Lund University, 2019; Lund University, 2021). The
160 University adheres to the Climate Frameworks and aims to reduce GHG emissions to become a
161 climate-neutral HEI by 2045. Measures include revising travel regulations and using climate
162 footprint calculations for necessary interventions (Sustainability Plan for Lund University 2020–
163 2026). In Canada, Concordia University and the University of British Columbia rank highly in The
164 Times Higher Education (THE) ranking for Sustainable Development Goal (SDG) 13 on Climate
165 Action. Concordia University aims to achieve carbon neutrality by 2040 with a Sustainability
166 Action Plan targeting emissions reduction and sustainable investments (Concordia University,
167 2020). The University of British Columbia's third climate action plan sets an emissions reduction
168 of 45% by 2030 and recognises climate justice as a guiding principle (University of British
169 Columbia, 2021).

170 In Asia, the National University of Singapore (NUS) aims to achieve carbon neutrality by 2030
171 with key sustainability programmes to mitigate carbon emissions and adapt to CC. NUS has
172 progressively reduced its CF since 2012 and has received the Green Mark Platinum Champion
173 Award (NUS Sustainability Strategic Plan 2017–2020 and Sustainability Roadmap, 2030).
174 Tsinghua University in China has reduced carbon emissions through energy-saving efforts since
175 2009, including geothermal wells, solar heaters, and energy-efficient light-emitting diode (LED)
176 lamps. The university promotes sustainable transportation and has made significant energy
177 savings (Zhao and Zou, 2015).

178 Despite the growing number of universities that have articulated decarbonisation plans, the
179 literature consistently reports that implementation remains challenging. Commonly cited
180 barriers include limited financial resources, bureaucratic complexity, and institutional inertia,

181 which can slow or constrain progress (Palanichamy and Goh, 2016; Worsham and Brecha, 2017;
182 Whitfield et al., 2022). High upfront costs associated with renewable energy investments often
183 compete with core academic priorities, while ageing and historically protected buildings tend to
184 be energy intensive and difficult to retrofit (Maistry and McKay, 2016; Battistini et al., 2023).
185 Together, these factors contribute to forms of carbon lock-in, whereby existing infrastructure and
186 decision-making pathways limit the pace of decarbonisation, even where institutional
187 commitment exists (Worsham and Brecha, 2017). Against this backdrop, analysing universities'
188 operational emissions and the obstacles they face is essential for understanding practical
189 pathways towards decarbonisation.

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

204 The study also emphasises data-driven approaches, advocating for robust carbon accounting and
205 benchmarking systems. This methodological focus ensures that universities can measure
206 progress accurately and adjust strategies accordingly, a practice that benefits any institution

207 pursuing decarbonisation. Furthermore, the discussion on behavioural change among students
208 and staff underscores the role of education and awareness in fostering a culture of sustainability,
209 reinforcing the idea that HEIs must lead by example. Ultimately, the study's findings extend
210 beyond individual cases, offering scalable solutions for reducing operational CF. Addressing
211 financial, administrative, and cultural hurdles, the study contributes to equipping HEIs with
212 actionable knowledge, making it a significant resource for advancing global sustainability in
213 higher education. Thus, the novelty of the paper lies in the fact that it studied situations in 40
214 countries, and touches upon the interconnectedness of sustainability awareness, cultural and
215 political dimensions, internal institutional structures, and technical approaches in achieving
216 decarbonisation goals.

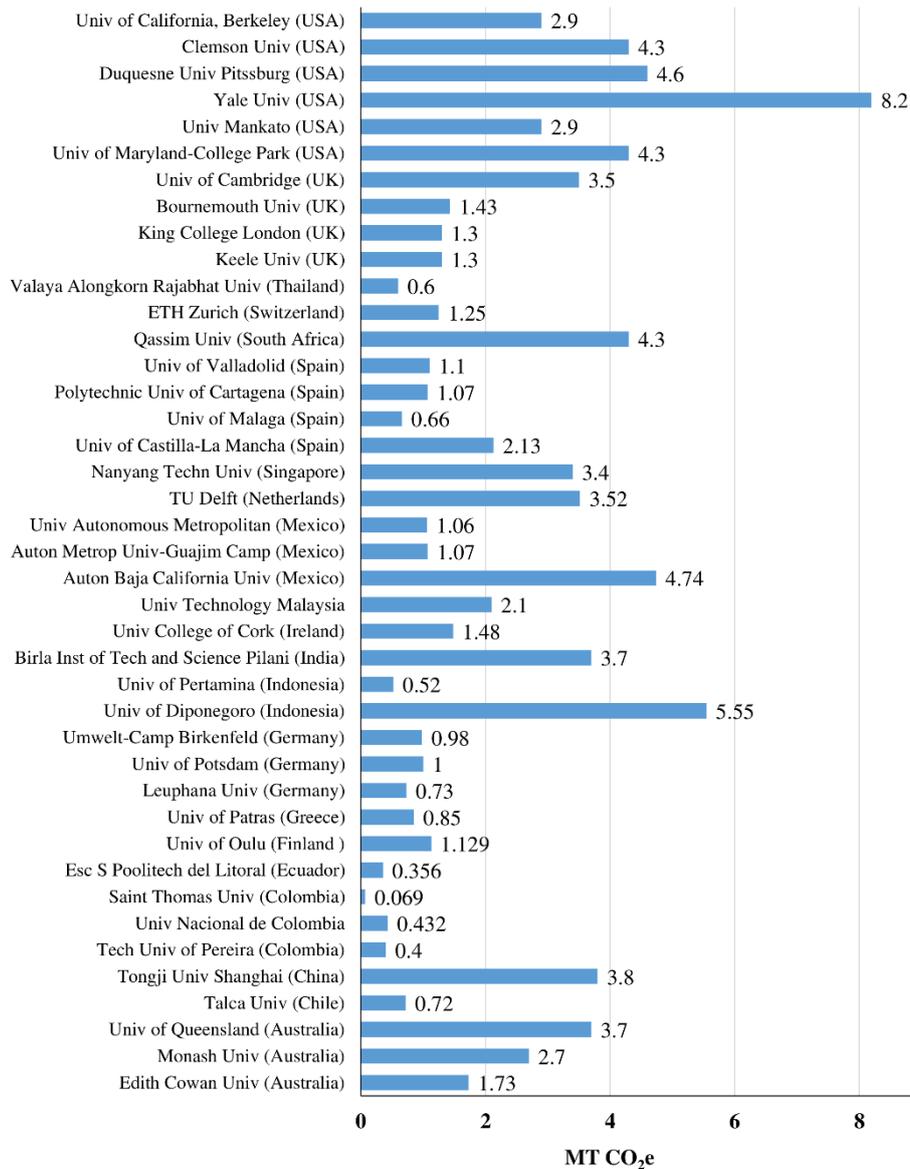
217 The paper is structured as follows: the next section deals with carbon emissions deriving from
218 university operations. After providing a background, emissions are classified and their calculation
219 outlined. Then, research objectives and this paper's contribution are given. The following section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

225 **Background: Carbon emissions from university operations**

226 HEIs are rapidly transforming and striving to enhance their overall quality in order to climb
227 national and international rankings. However, this drive for excellence often leads to substantial
228 resource consumption and increased GHG emissions, adding to an already overburdened planet
229 (Kulkarni, 2019). To achieve climate neutrality, HEIs should assess their current environmental
230 performance by calculating their CF to determine their GHG emissions (El Geneidy et al., 2021).
231 With an updated assessment, HEIs can formulate policies and implement practices aimed at
232 reducing emissions and promoting sustainability (da Silva et al., 2023). The CF is a valuable

233 decision-making tool, offering a concrete basis for comparing the environmental impact of
234 institutional activities with those of other academic institutions. As such, it is essential for HEIs to
235 take the lead in measuring, monitoring, and reducing their CF as part of their role as sustainable
236 organisations (Valls-Val and Bovea, 2021, 2022).

237 Despite the fact that various universities are developing plans to minimise GHG emissions, only a
238 small minority record and publish complete carbon inventories. In some cases, reports are only
239 available in local languages, limiting global accessibility (Helmets et al., 2021). Although
240 comparing emissions and drawing firm conclusions can be difficult, researchers have attempted
241 to capture and analyse available data. Based on a review of the literature, **Figure 1** highlights
242 these efforts by presenting per capita emissions per year rather than total emissions, from a
243 sample of universities. This is due to the wide variability in measurement methods and
244 institutional capacities. The educational process itself contributes to environmental impacts
245 through construction projects and day-to-day operations (Riddell et al., 2009). HEIs operate as
246 complex ecosystems (Gu et al., 2018), and their functions—education, research, governance, and
247 enterprise—all influence their GHG emissions. Teaching activities, in particular, have a significant
248 impact, requiring not only physical infrastructure such as libraries and lecture theatres, but also
249 a wide range of support services, including wellness, sports, social services, retail, and food and
250 beverage outlets to support student wellbeing (Robinson et al., 2018). **Figure 1** also illustrates
251 the significant variation in per capita carbon emissions among universities, even within the same
252 country. For example, in the United States (US), per capita emissions range from 2.9 to 8.2 tons
253 CO₂, making it difficult to draw valid conclusions at the national level.



254

255 **Fig. 1.** Annual HEIs' emissions per capita* per year (metric tons CO₂e) (years 2013-2022).
 256 *denotes per capita (as the sum of students and employees/staffs/residents). Source: authors,
 257 based on data from Valls-Val and Bovea 2021; Cano et al. 2022; and Adeyeye et al. 2023.

258 **Carbon emissions classification**

259 CF calculation involves categorising emissions and assigning them to specific **Scopes**. One of the
 260 most widely adopted frameworks for this is the GHG Protocol Corporate Standard, developed by
 261 the World Business Council for Sustainable Development and the World Resources Institute (WRI
 262 and WBCSD, 2013). This standard enables institutions to define their operational boundaries for
 263 'scoping' emission sources, helping to avoid double counting of emissions (Vrachni et al., 2022).

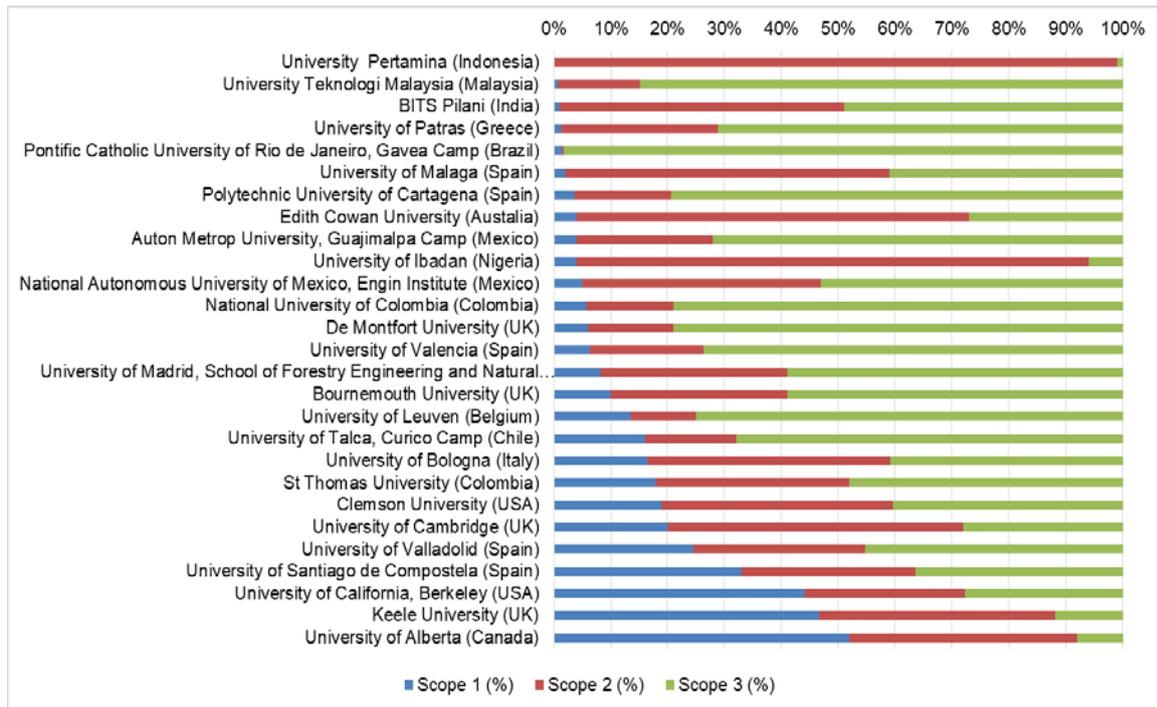
264 **Figure 2** illustrates the designated emission categories in relation to the operations of
 265 educational institutions, as outlined by the corporate GHG Protocol Standard.



266

267 **Fig. 2. Scopes** of emissions according to the GHG Protocol Corporate Standard. Source: authors,
 268 based on data from WRI and WBCSD (2013).

269 Three main **Scopes** can be distinguished. **Scope 1** refers to emissions directly caused by on-site
 270 fossil fuel combustion, such as for electricity, heat, or steam production, as well as emissions from
 271 transportation, materials, waste, and members of the campus community. It also includes
 272 unintentional leaks. **Scope 2** addresses indirect emissions associated solely with the production
 273 of purchased energy—emissions generated during the production of imported electricity, heat,
 274 or steam. **Scope 3** encompasses a broader range of indirect emissions, including those from
 275 business travel, outsourced activities, and waste management (Vrachni et al., 2022; Kiehle et al.,
 276 2023). Although GHG emissions are grouped into these three **Scopes**, fully attributing and
 277 accounting for the total emissions produced by an organisation can be highly complex. **Scope 1**
 278 and **Scope 2** emissions are generally easier to identify and calculate, whereas **Scope 3** emissions
 279 vary significantly depending on the institution (da Silva et al., 2023). Trends in emissions by
 280 **Scope** (expressed as percentages) show that, in most cases, emitters in developed countries
 281 report a higher proportion of emissions in **Scope 1** (**Figure 3**). Furthermore, a higher share of
 282 emissions in **Scope 1** typically corresponds with a lower proportion in **Scope 3**.



283

284 **Fig. 3.** Classification of HEIs emissions by *Scope*. Source: authors, based on data from Cano et al.
 285 (2022).

286 Overall, the analysis reveals significant variation in the distribution of emissions across the three
 287 *Scopes*. In most cases, institutions in developed countries report a higher share of *Scope 1*
 288 emissions, reflecting direct energy use for heating, transport, and on-site operations. *Scope 2*
 289 emissions, mainly from purchased electricity, account for a moderate share, while *Scope 3*
 290 emissions (indirect sources such as commuting and procurement) vary widely depending on data
 291 availability and reporting practices. To simplify comparison, **Table 1** summarises the main
 292 ranges observed across the reviewed institutions.

293 **Table 1.** Summary of typical minimum, maximum, and average proportions of institutional GHG
 294 emissions by *Scope*, based on data from the reviewed universities (see also **Figure 3**). ‘Typical’
 295 minimum and maximum values refer to the lower and upper bounds observed after excluding
 296 extreme outliers reported in a small number of cases, in order to provide indicative ranges rather
 297 than absolute extremes. Source: authors, based on Cano et al. (2022).

Emission scope	Typical minimum (%)	Typical maximum (%)	Mean/median (%)	Main sources
<i>Scope 1</i>	35	65	≈ 50	Direct fuel use, campus transport, heating
<i>Scope 2</i>	15	40	≈ 25	Purchased electricity and heat

Scope 3	10	50	≈ 25	Commuting, procurement, waste, investments
----------------	----	----	------	--

298

299 A compiled dataset on CO₂ emissions across operational categories from different universities
300 revealed a wide range of values (**Table 2**) (Letete et al., 2011; Gu et al., 2019; Clabeaux et al., 2020;
301 Ullah et al., 2020; Daglioglu, 2021; El Geneidy et al., 2021; Naderipour et al., 2021; Varon-Hoyos
302 et al., 2021; Zayit et al., 2021; Cano et al., 2022; Samara et al., 2022; Battistini et al., 2023). More
303 than 20 categories were identified as operational sources of CO₂ emissions, although not all were
304 consistently reported across institutions (**Table 2**). The primary sources of emissions included:
305 staff and faculty air travel (221.6–74,003.8 mt CO₂), boilers and heating systems (2,143–34,547
306 mt CO₂), food, canteen, and catering services (30.56–18,463.23 mt CO₂), wastewater treatment
307 (10.2–13,732.31 mt CO₂), trains, buses, and other land transport (4.21–11,194 mt CO₂), leakages
308 and refrigerants (3.5–6,729 mt CO₂), commuting by students and staff (3.42–6,654 mt CO₂),
309 electricity use (0.678–2,938 mt CO₂), travel-related emissions (0.07–1,303.94 mt CO₂), water
310 usage (0.0462–1,160 mt CO₂), solid waste (0.027–745.58 mt CO₂), and information technology
311 (IT) and paper-related consumption (0.0016–504.65 mt CO₂). Correlation analysis among the
312 emission **Scopes** showed weak to moderate relationships: **Scope 1** and **Scope 2** ($r = 0.60$), **Scope**
313 **1** and **Scope 3** ($r = 0.31$), and **Scope 2** and **Scope 3** ($r = 0.55$).

314 **Table 2.** Range of CO₂ emissions from different operations at HEIs. Source: authors, based on data
315 from Letete et al. (2011); Gu et al. (2019); Ullah et al. (2020); Clabeaux et al. (2020); Daglioglu
316 (2021); El Geneidy et al. (2021); Naderipour et al. (2021); Varón-Hoyos et al. (2021); Zayit et al.
317 (2021); Cano et al. (2022); Samara et al. (2022); and Battistini et al. (2023).

Operation	Range (mt CO₂)	
	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

Operation	Range (mt CO ₂)	
	Min	Max
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

318

319 **Carbon emissions calculations**

320 In recent years, analytical methods for calculating carbon emissions in HEIs have gained
321 importance, and various approaches have been developed. However, progress in evaluating the
322 broader environmental impact of these institutions remains limited (Kulkarni, 2019; Naderipour
323 et al., 2021). Traditionally, an organisation’s CF is calculated using either the process-based life
324 cycle assessment (LCA) approach, which estimates emissions at each stage of a system, or the
325 environmentally extended input-output (EEIO) approach, which links economic consumption
326 with environmental impacts. A hybrid method—environmentally economic input-output life
327 cycle assessment (EIO-LCA), also referred to as hybrid-LCA—combines process-LCA and EEIO to
328 leverage the strengths of both models (El Geneidy et al., 2021). Several universities have adopted
329 this hybrid method successfully due to its flexibility in integrating best practices and its
330 adaptability to the specific operational characteristics of individual institutions (Kiehle et al.,
331 2023). Key regulatory frameworks cited in the literature include the GHG Protocol (2004), ISO
332 14064-1 (2006), ISO/TR 14069 (2013), PAS 2050 (2011), and PAS 2060 (2014) (da Silva et al.,
333 2023) (**Table 3**). Across these frameworks, six main properties can be distinguished: (1) the
334 scope of emissions considered (organisational vs product-specific); (2) the methodological basis
335 (life-cycle vs operational accounting); (3) the degree of verification required; (4) the level of

336 prescriptiveness and flexibility; (5) the intended audience or organisational type; and (6) the link
 337 with international reporting initiatives. This typology provides a clearer overview of how the
 338 standards collectively shape carbon accounting practices within HEIs. These frameworks provide
 339 essential guidance for assessing and managing GHG emissions, supporting universities in their
 340 efforts to reduce their CF.

341 **Table 3.** Some regulatory frameworks and international guidelines for the calculation of
 342 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 (GHG, 2004).
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 (ISO 2006).
ISO/TR 14069:2013	For direct and indirect GHG emissions, ISO/TR 14069:2013 outlines the principles, concepts, and methods (ISO, 2018).
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 (BSI, 2011).

Framework	Description
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 (BSI, 2014).

343

344 The GHG Protocol Corporate Standard is generally preferred for calculating emissions within
345 HEIs (Kiehle, 2021; Naderipour et al., 2021; Valls-Val and Bovea, 2021). This standard clearly
346 defines the requirements for emissions in *Scopes 1* and *2*, but *Scope 3* has fewer requirements,
347 permitting the inclusion of selected indirect emissions that are not energy-related. As a result,
348 university carbon emissions are often calculated based on individual experiences, published case
349 studies, or self-defined rules, due to the absence of a universally recognised standard for
350 universities (Helmerts et al., 2021; Kiehle et al., 2023). Accurately and efficiently calculating the
351 CF of HEIs requires specialised assessment tools. Existing tools for CF calculation vary in terms of
352 inputs (source and emission factors) and outputs (results) and are not universally customisable
353 to accommodate universities worldwide, including *Scopes 1, 2*, and *3* (Helmerts et al., 2021; Valls-
354 Val and Bovea, 2021). To address this gap, Valls-Val and Bovea (2022) introduced CO2UNV, a CF
355 assessment tool specifically designed for universities. This fully configurable tool can
356 accommodate any case study, irrespective of emission sources and factors. Currently, CO2UNV
357 exists as an Excel prototype but requires further development into a user-friendly online tool
358 (Valls-Val and Bovea, 2022). The literature review reveals that the CF evaluation process offers
359 valuable insights into the various emissions categories that can be included or excluded.
360 However, significant differences in results across institutions complicate comparisons. Different
361 universities employ individual methods, underscoring the need for a unified approach and
362 standardised guidelines. Such standardisation would enhance comparability and enable the
363 effective evaluation of emissions reduction policies and practices (Kiehle et al., 2023). Therefore,
364 the creation of a globally accepted tool, specialised for HEIs, is crucial to standardise emissions
365 measurement and facilitate comparative analysis.

366 **From literature to research objectives**

367 The reviewed literature demonstrates that while numerous frameworks and tools exist to
368 calculate institutional CFs, there remains limited understanding of how universities translate
369 these standards into effective operational strategies and what are the barriers with ways to
370 address them. Previous studies highlight that institutional culture, leadership commitment, and
371 stakeholder engagement are decisive factors influencing the success of decarbonisation
372 initiatives in HEIs (Maistry and McKay, 2016; Battistini et al., 2023; Leal Filho et al., 2023a). These
373 insights suggest that organisational and governance dimensions are as critical as technical ones.

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

378 **Methods**

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

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

390 **Case studies**

391 The methodology followed in this study took into account Yin's (2017) approach to case study
392 research. A total of 22 publications featuring single or multiple case studies were selected with
393 the goal of gathering evidence to illustrate the best practices in decarbonisation efforts at
394 universities worldwide. The entire team of authors, all experts in the field of sustainability and
395 decarbonisation, collaborated throughout the process to ensure a robust selection of case studies
396 for the review of experiences which is inclusive. To identify relevant case studies, the team
397 utilised reputable academic databases, including Web of Science, Scopus, and Google Scholar,
398 employing search terms such as 'green campus', 'sustainable campus', 'greenhouse gas
399 emissions', 'carbon footprinting', 'climate action', 'greenhouse gas inventories', and their
400 appropriate combinations. In this study, the term "case studies" is used to refer to literature-
401 based analytical exemplars rather than in-depth institutional case studies grounded in primary
402 organisational data or institutional CF reporting. The selected cases are drawn from peer-
403 reviewed publications that document decarbonisation practices in HEIs, and they are used to
404 illustrate common approaches, barriers, and enabling factors across different contexts. Analytical
405 depth is achieved through cross-case comparison and synthesis of reported experiences, rather
406 than through institutional triangulation with additional documentary sources. This approach was
407 adopted to ensure consistency and comparability across cases and to remain aligned with the
408 exploratory and mixed-methods design of the study.

409 The screening process involved reviewing the titles and abstracts of identified publications to
410 ensure a broad geographical representation of the cases selected. This step was carried out
411 collectively by the authors, ensuring that the chosen publications reflect diverse global
412 perspectives. The final set of case studies was selected through consensus among the authors,
413 with the aim of ensuring a balanced representation of exemplary cases, rather than pursuing a
414 comprehensive or systematic literature review. The focus was on identifying and presenting
415 cases that provide valuable insights into best practices, barriers faced by institutions, and

416 recommendations for overcoming these challenges. This selection process benefited from the
417 collective expertise of the authors, who carefully evaluated each case's relevance to the study's
418 objectives.

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

425 **Survey on barriers to decarbonisation in higher education**

426 To complement the review and analysis of case studies, a survey was used, aimed at investigating
427 the barriers to decarbonisation in higher education, with a particular focus on reducing CO₂
428 emissions from university operations. The survey was run in parallel to the case studies, and
429 developed collaboratively by the research team, leveraging the expertise of all co-authors. The
430 questions were original and specifically designed for this study, based on the authors' prior
431 research and experience in sustainability and decarbonisation within HEI underpinned by the
432 literature.

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

441 Survey research is, in most cases, the best means of collecting original data on populations that
442 are too large for direct observation (Babbie, 2013), and it has been developed and widely applied
443 in university and educational contexts (Lozano et al., 2015; Ogle et al., 2023). Our methodological
444 approach ensured that the survey was well-suited to addressing the research objectives and
445 gathering meaningful insights into the challenges faced by universities in their decarbonisation
446 efforts. The questionnaire design builds on previous survey-based work by the authors (Leal
447 Filho et al., 2023b, 2025), drawing on established approaches commonly used in studies of
448 sustainability and decarbonisation in HEIs. The team members sent it to their available expert
449 network contacts and email lists. A total of 136 questionnaires from 40 countries have been
450 received. Incomplete or no answers were discarded.

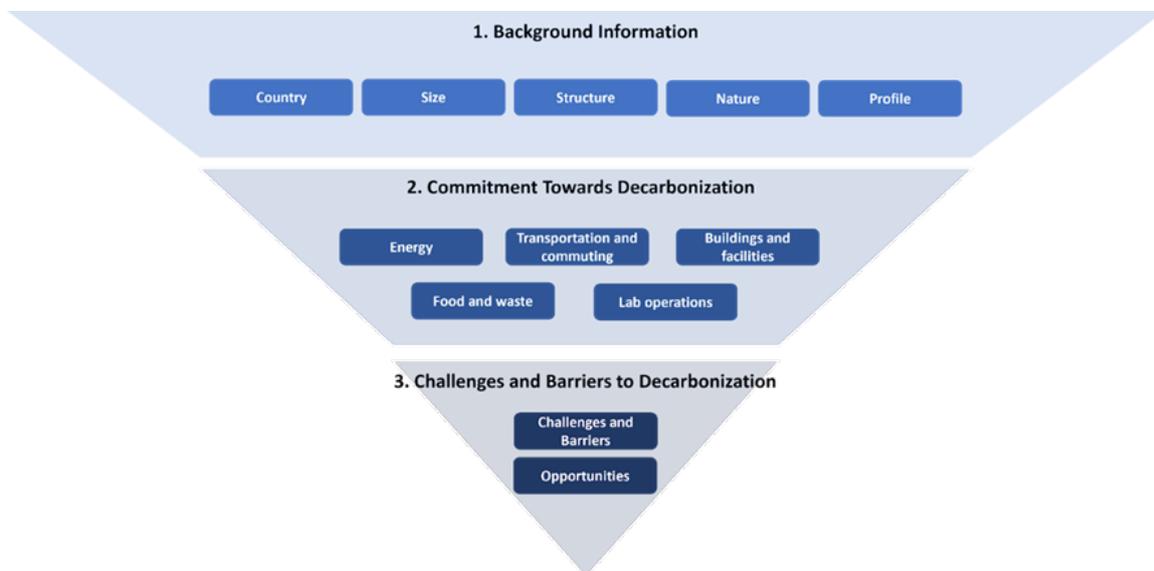
451 The questionnaire was structured in three different sections:

452 i. Background Information. The first section of the survey included questions designed to
453 characterize the sample, covering the institution's country, size, campus structure, nature and
454 profile, as well as the respondent's position within the university and their gender.

455 ii. Assessment of the Institution's Commitment Towards Decarbonisation. The second section
456 focused on specific aspects of the institutions' decarbonisation efforts, covering the following
457 topics: Energy (reducing energy consumption and GHG emissions on campus, and using
458 renewable energy sources); Transportation and Mobility (reducing carbon emissions from
459 student and staff commuting, promoting sustainable campus mobility initiatives, and supporting
460 sustainable business travel practices); Buildings and Infrastructure (certification of sustainable
461 buildings, facility retrofits, and energy efficiency); Food and Waste (reducing carbon emissions in
462 university dining services, tracking emissions related to food production and transportation,
463 minimizing food and packaging waste, and managing waste disposal and recycling); and
464 Laboratory Operations (chemical waste management and energy efficiency).

465 iii. Challenges and Barriers to Decarbonisation in Higher Education. The final section of the survey
466 focused on identifying the challenges and barriers encountered by HEIs in the decarbonisation
467 process, as well as exploring opportunities for improving their performance.

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



469
470 **Fig. 4.** Survey design. Source: authors.

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

477 The questions related to barriers were designed using a Likert-like scale. Responses were
478 assigned numerical values (to a very great extent = 5; to a great extent = 4; to a moderate extent
479 = 3; to a little extent = 2; not at all = 1), and average scores were calculated. In addition to the
480 Likert scale, respondents were able to indicate additional barriers or challenges through the
481 “other aspects” response option, thereby capturing contextual elements not included in the
482 predefined categories and enriching the interpretation of the results.

483 **Results and Discussion**

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

485 **Case studies**

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

491 **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. (2014)	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 (2014)	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. (2015)	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.

Reference	Study country	Topics	Best practices	Barriers	Additional suggestions for implementation
#4. Maistry and McKay (2016)	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 (2016)	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.
#6. Bulunga and Thondhlana (2018)	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).	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.

Reference	Study country	Topics	Best practices	Barriers	Additional suggestions for implementation
				Inappropriate circuit switches (shared switches for more than one device or lighting).	
#7. Park and Um (2018)	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. (2018)	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. (2019)	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	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.

Reference	Study country	Topics	Best practices	Barriers	Additional suggestions for implementation
			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.		
#10. Horan et al. (2019)	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.
#11. Barron et al. (2020)	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	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.

Reference	Study country	Topics	Best practices	Barriers	Additional suggestions for implementation
				engage in the learning process. Other policies and criteria could be seen as more simple than ICP.	
#12. Rojas-Vargas et al. (2020)	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. (2020)	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. (2021)	Mexico	Use of structured decision tool to choose priority investments in photovoltaic	AHP-RIM to define the order of installation of photovoltaic systems in the	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.

Reference	Study country	Topics	Best practices	Barriers	Additional suggestions for implementation
		energy at a university.	creation of sustainable university campuses.		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. (2021)	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.
#16. Yasuoka et al. (2021)	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. (2021)	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. (2022)	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.

Reference	Study country	Topics	Best practices	Barriers	Additional suggestions for implementation
					Need for behavioural change. To define framework to address indirect emissions sources.
#19. Cano et al. (2022)	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. (2022)	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. (2022)	Spain, Switzerland, UK, Italy, The	To assess the steps that global health institutions are taking to cut	An essential success component consists in including all staff, researchers, and students	Significant emissions from air travel.	Engaging people. Working with collaborators.

Reference	Study country	Topics	Best practices	Barriers	Additional suggestions for implementation
	Netherlands, Germany	their own operational GHG emissions and to identify the aids and impediments to attaining decarbonization objectives.	in the institution's sustainability approach.	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.	Taking concrete and rapid action.
#22. Battistini et al. (2023)	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.

493 As part of efforts to advance the Sustainable Development Goals (SDGs), greater emphasis
494 on sustainability issues in higher education programmes (Shulla and Leal Filho, 2023) will
495 contribute to raising awareness about decarbonisation and the pursuit of carbon
496 neutrality within HEIs (Leal Filho et al., 2021). One example of such an initiative is the
497 'Carbon Literacy Training' offered by Nottingham Trent University (2021), which
498 provides educators, communities, organisations, and students with essential carbon
499 literacy knowledge (Leal Filho et al., 2021; Nottingham Trent University, 2021). The
500 training equips participants with the necessary information to make informed decisions
501 regarding climate solutions, ultimately contributing to a brighter, more sustainable
502 future.

503 Other studies highlight awareness as a crucial element in implementing action. For
504 instance, Campos-Guzmán et al. (2021)(#14) and Rojas-Vargas et al. (2020)(#12) found
505 that a lack of interest in food waste often results in significant quantities of food being left
506 uneaten, suggesting that capacity-building is key to improving responses to food waste
507 issues. Zheng et al. (2021)(#17) identified that behaviour changes in air conditioning
508 usage, food consumption, and the adoption of electric bicycles are important factors in
509 reducing emissions. Additionally, Bulunga and Thondhlana (2018)(#6) concluded that
510 providing energy-saving tips, combined with regular feedback and incentives, can result
511 in reductions in energy use in university residences. Beyond knowledge and awareness,
512 some studies highlight the significance of cultural and political factors in driving climate
513 action within HEIs. Battistini et al. (2023)(#22) recommend that cultural differences be
514 taken into account in multi-campus universities.

515 Political factors also play an important role in decarbonisation efforts. For instance,
516 Franco et al. (2022b) recommend assessing the availability and willingness of municipal
517 governments to participate in developing transition teams. Furthermore, these authors

518 suggest that within HEIs, transition teams should be empowered to make necessary
519 changes and implement new strategies.

520 The internal structure of universities is also crucial to decarbonisation efforts. For
521 example, some studies report challenges in obtaining data on carbon emissions necessary
522 for calculating CF or GHG inventories. Battistini et al. (2023)(#22) highlight that
523 refrigerant gases, in particular, present significant difficulties. This may also include
524 aspects related to **Scope 3** emissions where the university may not have control. Maistry
525 and McKay (2016)(#4) note that personnel can either facilitate or hinder implementation,
526 recommending actions such as hiring, training, and raising awareness, with the
527 appointment of energy champions at the highest organisational levels. Similarly,
528 Palanichamy and Goh (2016)(#5) suggest a phased approach to implementing
529 photovoltaic (PV) systems across campuses.

530 From a technical perspective, several methods have been tested to prioritise actions for
531 decarbonisation. For example, Campos-Guzmán et al. (2021)(#14) employed the
532 Analytical Hierarchy Process (AHP) to address financial constraints in the simultaneous
533 installation of photovoltaic systems. According to Timmons and Weil (2021), the main
534 decarbonisation strategies for HEIs, in line with CC mitigation, involve renewable
535 electricity generation, electrification of end uses, and energy efficiency, with the optimal
536 combination of these strategies being essential. While the complexities of decarbonisation
537 are acknowledged, the authors emphasise that the most crucial benchmark for HEIs is the
538 expected cost of grid-purchased carbon-free electricity.

539 They suggest that the focus should be on achieving decarbonisation targets at the lowest
540 possible cost, rather than pursuing financial rewards from reducing fossil fuel use. This
541 represents a significant shift in objectives for many HEIs and calls for a new approach to
542 institutional planning, which must now account for phasing out fossil fuel-dependent
543 infrastructure. Consequently, greater investments in energy efficiency may be justified

544 when considering total decarbonisation rather than individual interventions based solely
545 on fossil fuel savings. Indeed, while individual actions can contribute to energy savings,
546 they are insufficient to achieve full decarbonisation (Franco et al., 2022a). Franco et al.
547 (2022a), in their study of student energy-saving behaviour at PXL University of Applied
548 Sciences in Belgium and the University of Caxias do Sul in Brazil, identified three key
549 dimensions influencing students' energy-related attitudes: the roles of citizens, scientists,
550 and government, which together explained 65.5% of the students' energy-related
551 attitudes. The study also revealed three dimensions of sustainable behaviour—
552 consumption of environmentally friendly goods, money-motivated behaviour, and home
553 energy conservation—which together explained 64.5% of the students' energy-related
554 behavioural intentions. The authors argue that these findings underscore the need to
555 engage key stakeholders in promoting decarbonisation efforts within HEIs, facilitating
556 societal progress. Carbon lock-in, the continued reliance on fossil fuel energy systems
557 despite the availability of low-carbon alternatives, presents a major obstacle to achieving
558 carbon neutrality in HEIs, even when there is public commitment to sustainability.

559 The long-term costs associated with carbon lock-in, such as the expense of offsetting
560 locked-in emissions, cannot be ignored and must be factored into decision-making
561 (Worsham and Brecha, 2017). A study by Horan et al. (2019)(#10), which aimed to
562 develop a method for quantifying the decarbonisation potential of technologies at Irish
563 Higher Education Campuses (HECs), revealed that decarbonisation methods involving
564 power generation could result in significant carbon savings. The study also highlighted
565 the potential for reducing carbon emissions related to water delivery. Findings indicated
566 a strong correlation between the gross internal area (GIA) of HECs and roof area, while
567 the correlation with parking area was less significant. This research suggests that urban
568 form plays a more important role in determining the parking area at HECs. The
569 methodology, which includes the use of open carpark areas, could also be applied to city-
570 scale investigations, promoting decarbonisation transitions beyond campuses.

571 Research on internal carbon prices (ICPs) in use at 11 United States HEIs revealed a
572 growing applicability of these tools (Barron et al., 2020)(#11). The study found that both
573 proxy carbon prices and carbon charges are already being implemented in several US
574 HEIs, signalling their potential to drive institutional change by encouraging the adoption
575 of low-carbon options. These tools help promote transparency, standardise decision-
576 making, and drive cost-effective use of resources, ultimately supporting HEIs'
577 decarbonisation goals, such as the adoption of net-zero building standards and the
578 promotion of electric vehicle use. In the context of decarbonisation, the concept of "smart
579 campuses" plays an important role in reducing carbon impacts (Kourgiozou et al., 2021).

580 HEIs in the United Kingdom and worldwide are increasingly integrating smart services
581 and Information and Communication Technologies (ICT) into their daily operations. A key
582 benefit of distributed energy generation is carbon and cost reduction, highlighting the
583 importance of driving the adoption of smart energy campuses. To enable this transition,
584 specific regulations for smart energy integration within HEIs are needed, alongside the
585 necessary infrastructure technologies to support energy efficiency programmes. Creating
586 a unified framework for smart campuses and energy systems, with energy storage playing
587 a pivotal role, is essential for advancing decarbonisation in university buildings. The
588 reduction of CF in global health institutions was examined by Whitfield et al. (2022)(#21),
589 who found that environmentally sustainable practices align with the core mission of
590 improving global health. Their study offers several recommendations for promoting
591 change, including engaging people through competency-building and collaborative
592 sustainability efforts, amplifying global partnerships, and prioritising specific carbon
593 reduction actions to ensure transparency.

594 A recent study by Leal Filho et al. (2023a) assessed the decarbonisation efforts of
595 universities across 40 countries and concluded that HEIs are making progress towards
596 decarbonisation, with renewable energy use becoming increasingly popular and the

597 reduction of carbon emissions seen as a priority. This aligns with the findings of the
598 European Parliament’s Committee on Development (DEVE) report, “Achieving the UN
599 Agenda 2030: Overall Actions for the Successful Implementation of the SDGs Before and
600 After the 2030 Deadline” (Shulla and Leal Filho, 2023), which identifies decarbonisation
601 as a critical component in achieving the SDGs and avoiding serious CC consequences in
602 the coming decades.

603 Afforestation and reforestation are also key strategies for offsetting CO₂ emissions
604 (Akbari, 2009), although their impact may be limited in some contexts. For example, at
605 universities in New Zealand and China, initiatives like tree planting have only yielded
606 partial results compared to other actions, such as reducing overseas travel (De Villiers et
607 al., 2014; Zheng et al., 2021)(#1)(#17). Cornell University’s main campus in the US has
608 implemented a sustainable design for carbon-neutral energy systems, relying primarily
609 on renewable and locally generated energy. This initiative could serve as a model for other
610 campuses and cities with similar characteristics (Tian et al., 2022)(#20). Developing
611 economies also provide examples of successful decarbonisation practices. Jordan
612 University of Science and Technology, despite being located in a semi-arid region, has
613 successfully greened its campus through an action-oriented approach, reducing water
614 usage, CO₂ emissions, and solid waste (Abu Qdais et al., 2019)(#9). In Malaysia, 16 HEIs
615 have implemented green practices, producing valuable data and insights for more
616 coherent policymaking at both domestic and global levels (Anthony, 2021).

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

619 **Box 1.** Summary of barriers to decarbonisation of HEIs expressed in the selected case
620 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

621

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

624 Temporal considerations also have to be considered. Although some of the case studies
625 pre-date recent global shifts such as the COVID-19 pandemic and the acceleration of
626 digital learning, their main conclusions remain applicable. The pandemic, for instance,
627 temporarily altered travel-related emissions but did not fundamentally change the long-
628 term structural challenges, such as energy systems, infrastructure, and governance,

629 identified in earlier studies. Thus, the lessons drawn from these cases continue to offer
630 relevant guidance for current and future decarbonisation strategies.

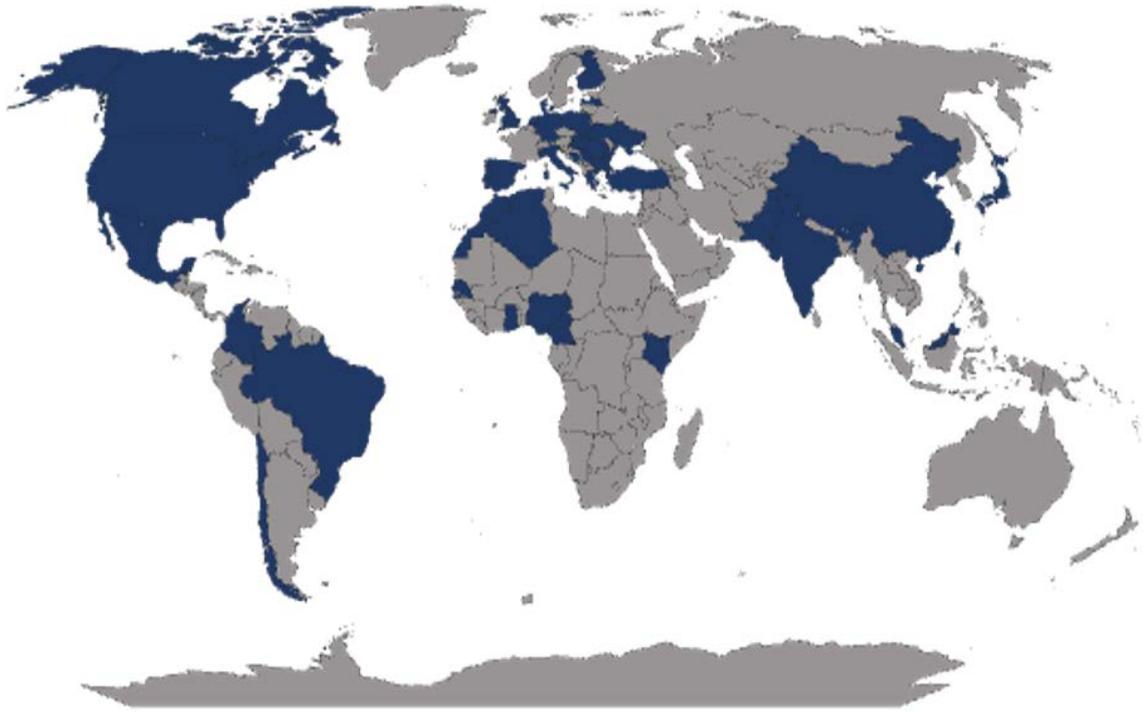
631 Considered together, these case studies are not intended to provide in-depth institutional
632 analyses based on primary organisational data, but rather to function as literature-based
633 analytical exemplars. Their value lies in the cross-case synthesis of peer-reviewed
634 evidence documenting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

639 **Survey**

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

642 **Respondents**

643 A total of 136 respondents from 40 countries completed the questionnaire with a
644 reasonable number of representatives from countries in Europe, Africa, North and South
645 America, and Asia (**Figure 5**) (**Table 4**). The sample covers countries with distinct
646 economic and social profiles. Most of the respondents attend public universities (77%) in
647 urban areas (76%).



648

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

650 **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

Country	Number of responses	Country	Number of responses
Finland	2	Taiwan	1
Germany	2	The Netherlands	1
India	2	Turkey	1
Japan	2	Ukraine	1
Malaysia	2		

651

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

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

Category	Answers	<i>n</i>	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

Category	Answers	<i>n</i>	Frequency (%)
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

666 The distribution of answers on the respondents' characteristics are indicated in **Table 7**.

667 The study attempted to gain insights into decarbonisation efforts of universities from a

668 multi- stakeholder perspective, however, most respondents are teaching and research

669 staff who are part of the HEI community and shared their experiences for a holistic view.

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

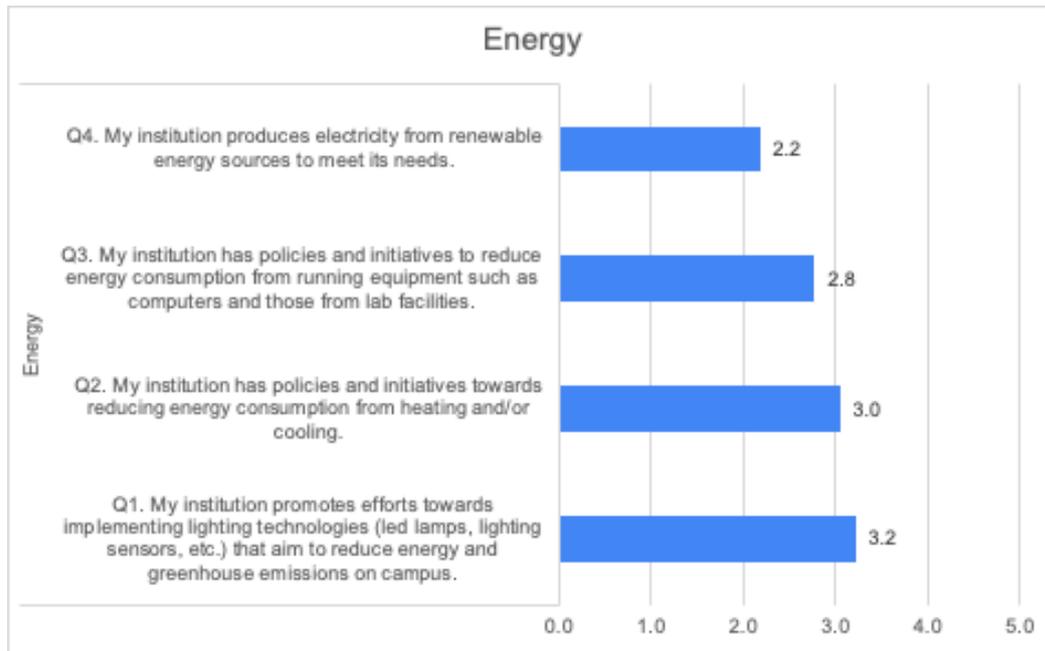
Position / Gender	Description	<i>n</i>	Frequency (%)
Respondent's position at HEIs	Teaching staff and researcher	73	54
	Student (Bachelor, Master, PhD, etc.)	21	15
	Teaching staff	18	13

Position / Gender	Description	<i>n</i>	Frequency (%)
	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

671

672 **Operations and practices**

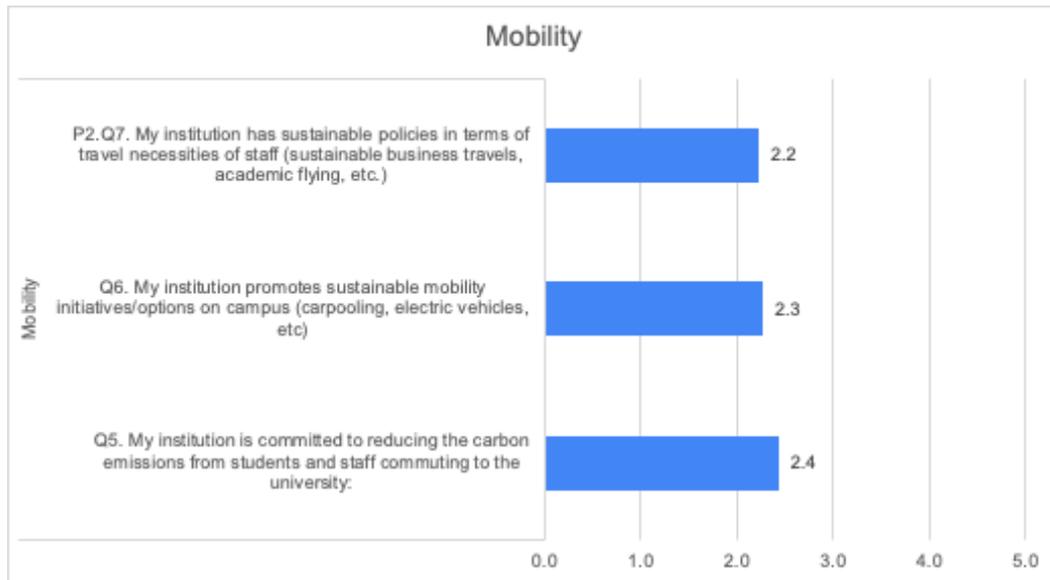
673 Regarding energy use (**Figure 6**), a few HEIs produce electricity from renewable energy
674 sources to meet their energy needs. Although the survey demonstrates that only to a
675 limited extent some HEIs are able to generate electricity, the strength of such a strategy
676 to reduce **Scope 2**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



686

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

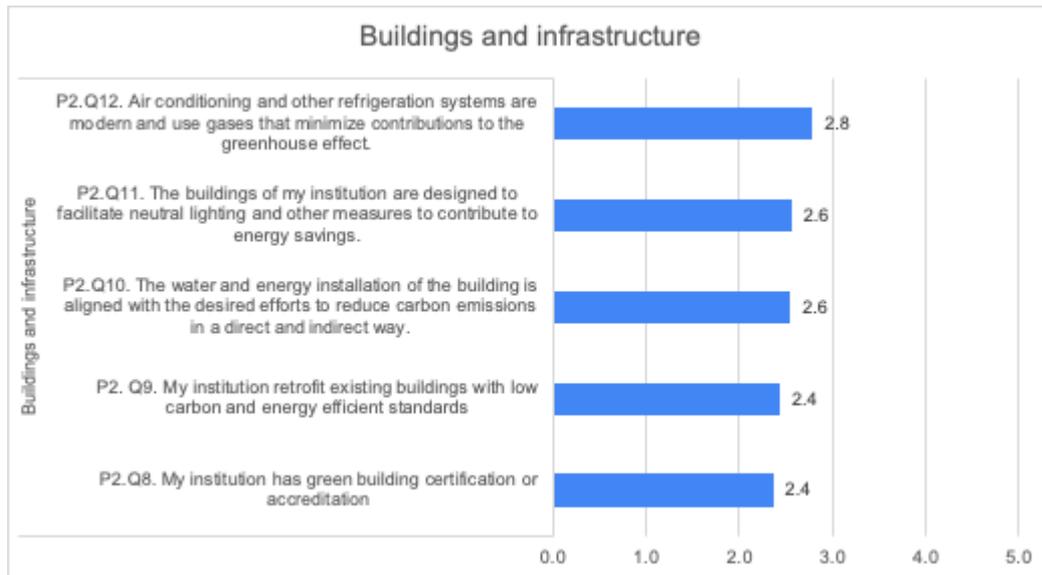
690 Commuting is also relevant in terms of GHG emissions. In comparison to energy demand,
 691 emissions from commuting are usually reported as **Scope 3** emissions. The attention
 692 devoted by HEIs to such types of emissions is lower than the efforts targeting energy
 693 efficiency and generation of electricity from renewable energy sources (**Figure 7**). To a
 694 limited extent, HEIs have sustainable policies that affect staff travel plans as part of their
 695 GHG emission reduction strategies. Promotion of sustainable mobility initiatives for staff,
 696 students or the general public are also part of the limited extent strategies targeting GHG
 697 emission reductions that have been identified by respondents. Measurements by
 698 Sangwan et al (2018) and Adeyeye et al (2022) confirm that HEIs' CF is composed to a
 699 great extent by commuting emissions.



700

701 **Fig. 7.** Barriers to decarbonisation – Mobility. Source: authors. Note: *I do not know* (Q5):
 702 5 respondents; *I do not know* (Q6): 5 respondents; *I do not know* (Q7): 15 respondents.

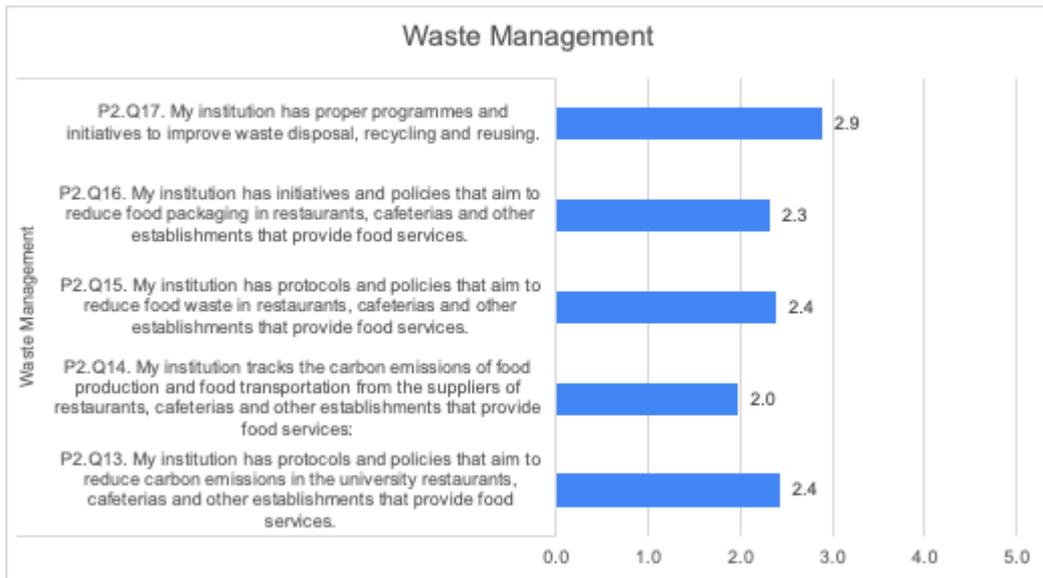
703 The respondents highlighted the use of refrigeration gases that minimise the contribution
 704 to greenhouse effect (**Figure 8**). This is interesting and could lead to the need to
 705 understand potential bias or group differences. Many countries adhered to the Kigali
 706 amendment to the Montreal Protocol recently, and reduction goals should lead to
 707 eliminating 80% of hydrofluorocarbon (HFC) gases by 2040. It is not expected that gases
 708 such as R134a and R410a are currently extensively phased out. Regarding energy
 709 consumption of refrigeration systems, Yasuoka et al (2021) bring the use of IOT to cut
 710 energy consumption. None of the literature case studies brought an example of action in
 711 this direction. The second ranked action was on lightning. However, Bulunga and
 712 Thondhlana (2018) brought the concerns of users with security hazards when switching
 713 lights off, which caused resistance to expected behaviour. On the other hand, examples of
 714 alternative sources of energy such as application of PV systems (Palanichamy and Goh,
 715 2016). Horan et al (2019) cite an example of implementation of PV and micro-wind
 716 turbines power generation. Campos-Guzmán et al (2021) recommend that when PV
 717 projects cannot be started at once, a staged implementation must be put in place.



718

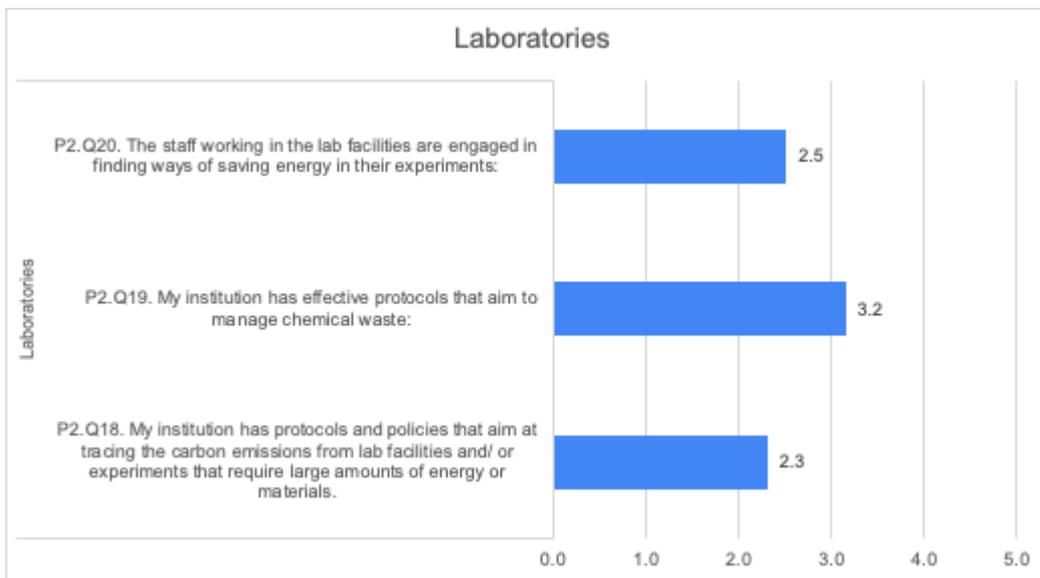
719 **Fig. 8.** Operations and practices – Buildings and Infrastructure. Source: authors. Note: *I*
 720 *do not know* (Q8): 35 respondents; *I do not know* (Q9): 27 respondents; *I do not know*
 721 (Q10): 22 respondents; *I do not know* (Q11): 17 respondents; *I do not know* (Q12): 27
 722 respondents.

723 Waste handling, disposal, recycling, is one of the main concerns in the survey, and food
 724 waste seems to be one of the main issues (**Figure 9**). Handling of waste is brought up as
 725 an important **Scope 3** emission category by several authors, such as Vrachni et al. (2022)
 726 and Kiehle et al. (2023). Food waste seems to be a special concern. Rojas-Vargas et al
 727 (2020) say that there is a general lack of interest in this source, and this is why it is still
 728 the reason for action. **Figure 10** shows the responses of the respondents regarding saving
 729 energy, managing chemical waste and reducing carbon emissions in the laboratories.



730

731 **Fig. 9.** Operations and practices – Waste Management. Source: authors. Note: *I do not*
 732 *know* (Q13): 27 respondents; *I do not know* (Q14): 34 respondents; *I do not know* (Q15):
 733 29 respondents; *I do not know* (Q16): 28 respondents; *I do not know* (Q17): 19
 734 respondents.



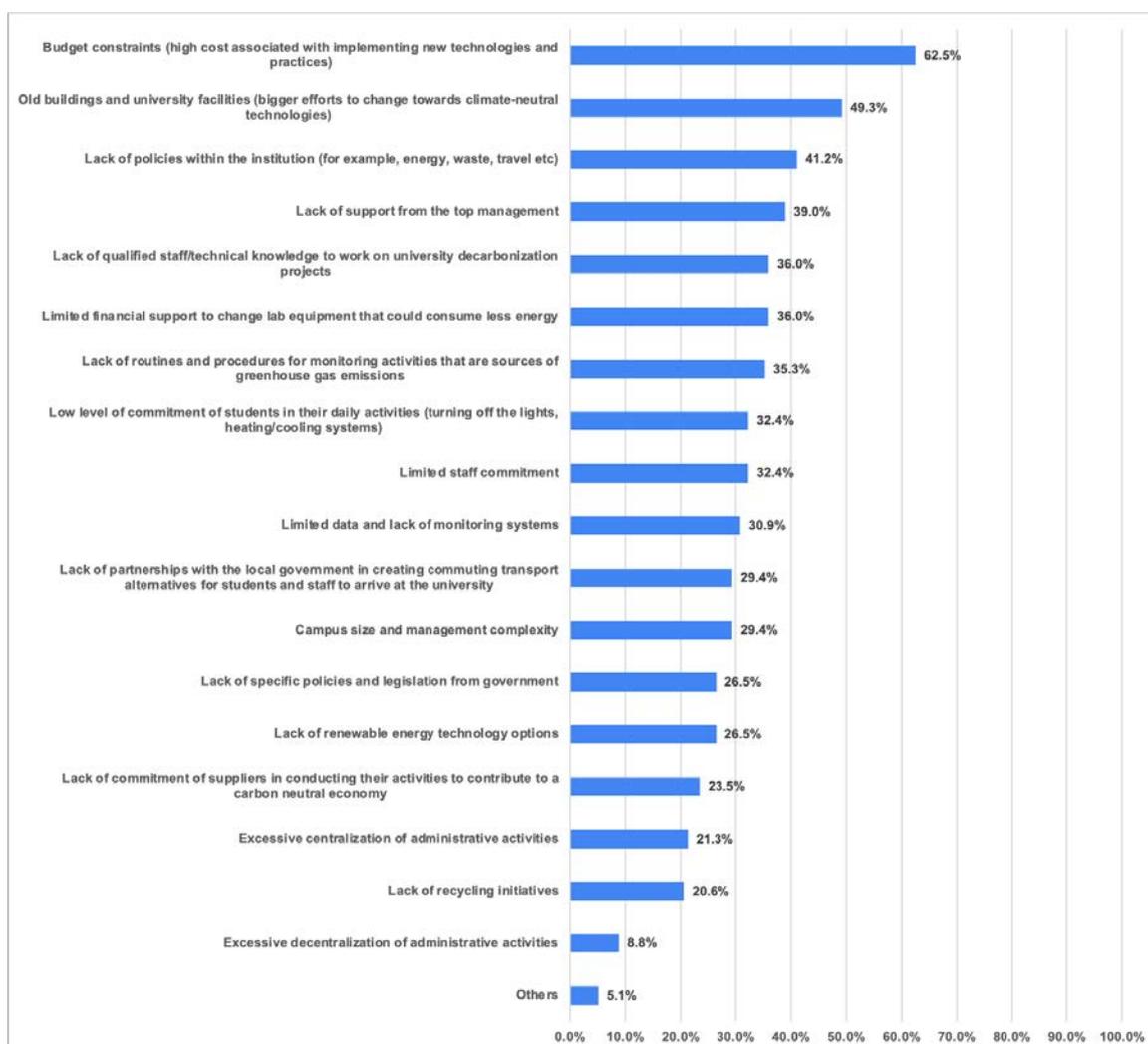
735

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

739 **Barriers to decarbonisation**

740 **Figure 11** shows the answer regarding the barriers to decarbonisation. It is important to
 741 note that the main barriers are managerial, such as limited budget, lack of managerial
 742 support, lack of qualification staff and lack of routines and procedures to get data on

743 emission sources. The only technical issue ranked among the most important ones is the
 744 existence of old buildings, which might be more difficult to retrofit. Historical and listed
 745 buildings are a challenge when it comes to decarbonisation in HEIs. Other technical
 746 barriers such as lack of renewable alternatives and campus site complexity are poorly
 747 ranked. Regarding lack of financial resources, Abu Qdais et al. (2019) remark the
 748 importance of finding win-win situations to make it easier to justify investments. Maistry
 749 and McKay (2016) recommend the assignment of an energy-champion at the highest level
 750 of the organisation to assure management is involved.



751

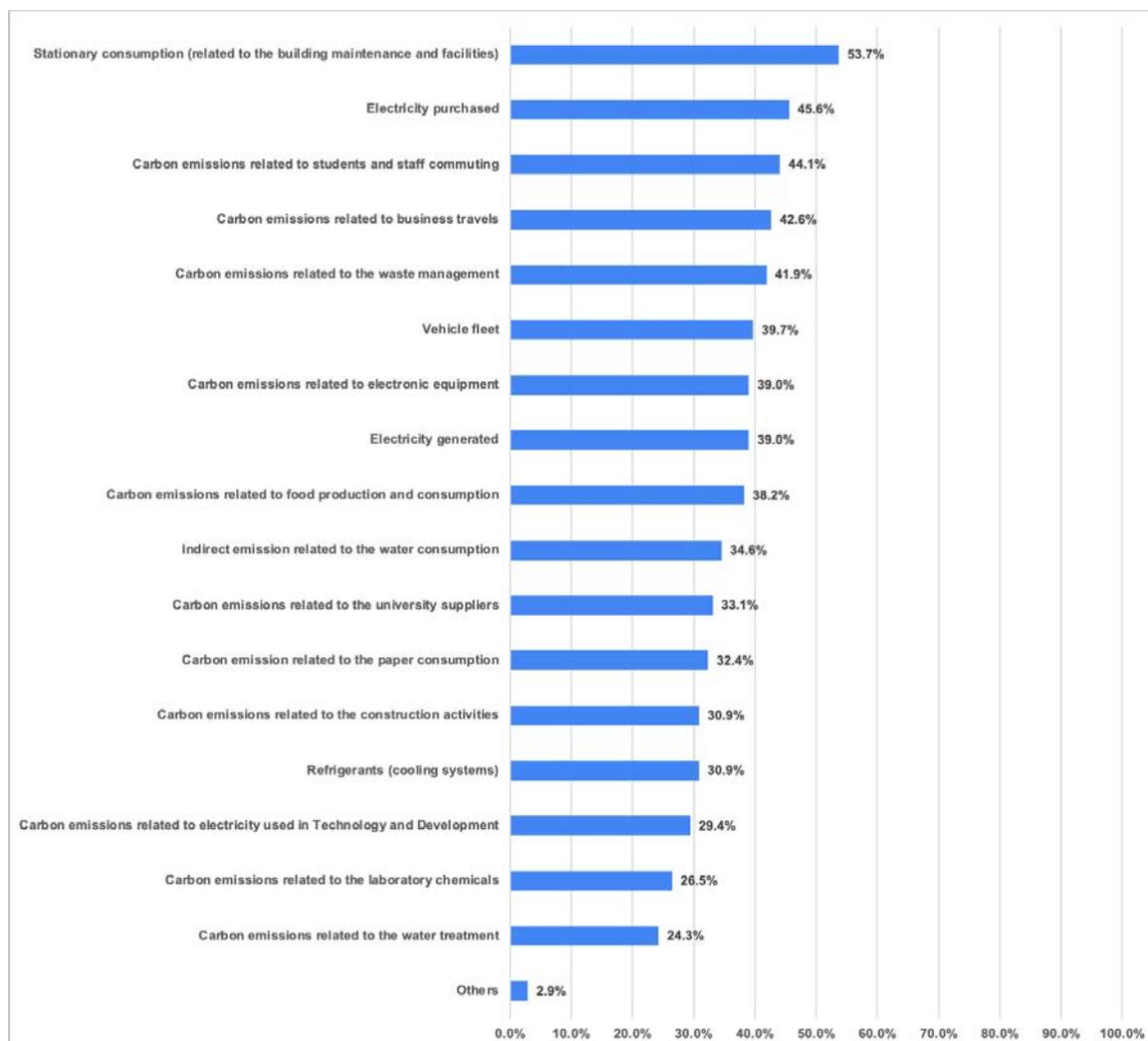
752 **Fig. 11.** Frequency of perceived challenges and barriers to campus decarbonisation (n =
 753 136). Source: authors.

754 The main barrier is budget constriction. A similar barrier is described by Whitfield et al
755 (2022) and Palanichamy and Goh (2016). Whitfield et al (2022) also quoted poor energy
756 efficiency of historic and protected buildings as one out of the barriers. It is interesting
757 that lack of policies and support by top management is not quoted in the case studies.
758 Limited staff commitment shows up in another form: resistance to change, reported by
759 Vásquez et al. (2015) and Whitfield et al. (2022). Lack of knowledge was an issue found
760 by Maistry and McKay (2016), and lack of monitoring routines seem to be the expression
761 of similar findings by Maistry and Annegam (2014) and Barron et al. (2020).

762 Stationary consumption and purchased electricity are graded as main opportunities for
763 emissions reduction. They seem to be related to heating in predominantly cold places and
764 air conditioning (refrigeration) in warmer weather. Stationary consumption seems to be
765 a priority in several institutions (**Figure 12**). However, there seems to be a gap regarding
766 refrigeration systems. Valls-Val and Bovea (2022) show that less than 40% of GHG
767 inventories at universities included emissions from refrigeration systems. Mobility apps
768 usually do not bring the real fuel and precise distances, making it difficult to measure.
769 Improvement methods would include electric vehicles and use of biofuels. Commuting
770 and business travels are also ranked as important opportunities. However, **Scope 3**
771 emissions are known to be challenging to measure (Klaassen and Stoll 2021; Stenzel and
772 Waichman, 2021).

773 Appropriate commuting measurement would involve getting information on routes,
774 mileage and transport modes (even if more than one mode) for each individual trip. This
775 seems to be not feasible. So, sampling and simplified methods have to be used, and the
776 validation is still a challenge. Kiehle et al. (2023), Pacca et al. (2024) and Veludo et al.
777 (2021) are some of the authors pointing this issue. In the case of business travels, air
778 tickets can come from different pockets – HEIs budget, projects budget, partnering, which
779 makes it difficult to gather information precisely, although estimation for each travel is

780 relatively simple. When dealing with car business travel, the use of taxi and vehicle
 781 features introduce imprecision in the estimation methods, particularly in countries where
 782 a variety of fuels are used.



783

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

786 Taken together, the survey results portray a consistent pattern of barriers and
 787 opportunities for decarbonisation within HEIs. Respondents across regions identified
 788 limited financial resources, weak managerial support, and insufficient staff training as the
 789 main obstacles to implementing effective emission-reduction measures. Technical
 790 barriers, such as ageing infrastructure and the lack of renewable alternatives, were
 791 considered secondary to organisational and cultural challenges. The results also show

792 that although energy and mobility remain the dominant emission sources, systematic data
793 collection and performance monitoring are often lacking, constraining evidence-based
794 decision-making. Overall, the findings emphasise that successful decarbonisation
795 depends as much on institutional commitment and governance mechanisms as on
796 technological innovation. This understanding provides the foundation for the following
797 section, which explores ways in which these barriers can be addressed.

798 **Overcoming structural and contextual barriers to decarbonisation in HEIs**

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

803 ***Standardising Carbon Accounting Practices.*** In line with the findings from the literature
804 review, the study recommends that universities adopt harmonised and transparent
805 approaches to carbon accounting. Existing standards such as the GHG Protocol (2024),
806 ISO 14064-1 (2006), and PAS 2060 (2014) provide valuable guidance, but their
807 application in HEIs remains inconsistent. Establishing a common framework specifically
808 tailored for HEIs would enable greater comparability of emissions data across institutions
809 and countries, improve benchmarking, and support more coherent monitoring of
810 progress towards carbon-neutral operations. Developing and sharing open-access tools
811 based on such standards would further strengthen transparency and encourage
812 institutional collaboration in decarbonisation efforts.

813 ***The Need for Cultural and Political Considerations.*** HEIs operate within diverse cultural
814 and political contexts, especially those with multiple campuses across regions or
815 countries. Cultural differences can influence attitudes toward sustainability, necessitating
816 tailored approaches to climate action (Battistini et al., 2023; Zheng et al., 2013). Politically,

817 both external support and internal governance structures play crucial roles. Mazhar et al.
818 (2017) identified governance and management as a critical success factor for successfully
819 embedding carbon management that are pertinent not just for the higher education
820 sector, but to organisations broadly. Public and municipal engagement is key to the
821 legitimacy and feasibility of decarbonisation projects (Zheng et al., 2021; Franco et al.,
822 2022b). Internally, transition teams should be empowered with decision-making
823 authority, free from bureaucratic constraints, to drive meaningful change (Franco et al.,
824 2022b).

825 ***The Need to Acknowledge Institutional Structures and Operational Constraints.*** The
826 effectiveness of climate action within HEIs is also shaped by their organisational
827 architecture. Several studies highlight the difficulties in accessing accurate data on carbon
828 emissions, especially regarding refrigerants and indirect emissions, which hampers the
829 creation of comprehensive carbon inventories (Battistini et al., 2023). Staff engagement
830 is equally critical—personnel can either enable or obstruct sustainability efforts
831 depending on institutional incentives and training opportunities (Maistry and McKay,
832 2016). Appointing energy champions at senior levels can help embed sustainability
833 within university governance.

834 ***The Need to Pursue Technical Pathways and Strategic Planning.*** Implementing
835 decarbonisation technologies in a resource-constrained environment requires careful
836 planning. Palanichamy and Goh (2016) proposed a phased approach to installing PV
837 systems, while Campos-Guzmán et al. (2021) used the AHP to prioritise interventions
838 based on feasibility and impact. Timmons and Weil (2021) argue that institutions should
839 pursue a combination of renewable energy generation, electrification of end uses, and
840 energy efficiency—focusing on achieving carbon neutrality at the lowest cost, rather than
841 prioritising immediate financial returns.

842 ***The Need for Institutional and Student Engagement.*** Behavioural change is another
843 lever for emissions reduction. Stakeholders including staff and students and leadership
844 engagement are key factors for carbon reduction in universities (Mazhar et al., 2017).
845 Franco et al. (2022a) found that students' energy-saving attitudes are shaped by their
846 perceptions of the roles of citizens, scientists, and governments. Their study identified
847 distinct behaviour patterns, such as eco-friendly consumption and conservation efforts,
848 demonstrating the need for stakeholder collaboration to embed decarbonisation into
849 campus life.

850 ***The Need to Acknowledge Carbon Lock-in and Long-Term Risk.*** One of the most
851 persistent challenges is carbon lock-in, the continued reliance on fossil fuel infrastructure
852 despite sustainability goals (Worsham and Brecha, 2017). Addressing this risk requires
853 long-term planning that anticipates the eventual decommissioning of high-emission
854 systems and embraces low-carbon alternatives at scale.

855 ***The Need for Innovative Practices and Institutional Learning.*** Several HEIs are
856 pioneering methods to overcome decarbonisation barriers. In Ireland, Horan et al. (2019)
857 developed a model to assess the carbon-saving potential of decarbonisation technologies,
858 using spatial data from rooftops and parking areas. In the US, ICP is gaining traction as a
859 mechanism to incentivise low-carbon decisions and promote transparency (Barron et al.,
860 2020). Similarly, the concept of “smart campuses” incorporating ICT and decentralised
861 energy systems, is proving essential to modern energy strategies in HEIs (Kourgiouzou et
862 al., 2021).

863 ***The Need to Combine Global and Local Learning.*** Notable case studies from both
864 developed and developing economies illustrate how different contexts adapt to shared
865 goals. Cornell University, US, has implemented a carbon-neutral energy system that
866 serves as a blueprint for others (Tian et al., 2022). In more resource-constrained settings,
867 Jordan University of Science and Technology has achieved sustainability gains in a semi-

868 arid environment (Abu Qdais et al., 2019), while Malaysian universities have adopted a
869 variety of green practices across 16 institutions (Anthony, 2021). Yet, some well-
870 intentioned actions, such as afforestation and reforestation, have shown limited impact
871 when compared to systemic interventions. De Villiers et al. (2014) and Zheng et al. (2021)
872 found that despite green surroundings, campuses in New Zealand and China remained
873 unsustainable due to high energy and travel emissions. These examples underscore that
874 effective pathways are highly context-dependent shaped by geographical, socio-
875 economic, and institutional conditions.

876 ***The Need for Specific Strategies.*** Internationally, decarbonisation is increasingly
877 embedded in sustainability frameworks. DEVE identified decarbonisation as one of the
878 six priority areas to meet the SDGs by 2030, emphasising the need for equitable and
879 sustainable energy infrastructures (Shulla and Leal Filho, 2023). Leal Filho et al. (2023a)
880 reaffirm that many universities are already progressing, particularly through increased
881 use of renewable energy and emissions reduction strategies.

882 Decarbonisation in HEIs requires more than isolated efforts. Addressing structural
883 inefficiencies, fostering institutional leadership, and aligning cultural and political
884 realities with technical capacity can accelerate progress. With concerted effort and shared
885 learning across borders, HEIs can overcome barriers and lead transformative climate
886 action in education and beyond.

887 As discussed above, advancing decarbonisation in higher education requires more than
888 isolated or technology-driven efforts such as addressing institutional inefficiencies,
889 promoting leadership that bridges academic and operational domains, and aligning
890 cultural and political realities with technical capacity. As the examples from diverse
891 regions show, effective strategies are inherently context-dependent so the strengthening
892 of international cooperation and knowledge exchange can accelerate collective learning

893 and support more equitable climate action across the HEIs so that they can act as catalysts
894 for transformative climate leadership within the sector and beyond..

895 **Conclusions**

896 Based on the empirical evidence from a worldwide survey of 136 respondents across 40
897 countries, and also from the thematic analysis of over 20 literature-based case studies,
898 this study underpins several important conclusions fitting the goal of mapping
899 operational decarbonisation strategies, constraints and institutional practices in HEIs.
900 The analysis shows that most of the surveyed institutions are committed to carbon
901 neutrality or to deep emission reductions focusing on **Scope 1** and **2** emissions. This is
902 demonstrably reflected in the data by widespread reporting of certain actions adopted.
903 As described in the responses given to the enquiry on energy system, a large number of
904 institutions are turning to renewable sources, with “on-site generation”—especially solar
905 PV—the most used strategy among survey responses and studies. Concurrently, the
906 information on campus operations indicates that ongoing energy-efficiency efforts are
907 nearly universal, reflected in reported actions—such as retrofitting the buildings and
908 integrating building management systems and LED lighting replacements—that
909 respondents correlate directly with the reduced emissions. However, the study also notes
910 that there are identifiable institutional structures and obstacles to it, which in turn
911 determine the way things are actually moving forward.

912 The data on governance and delivery revealed that, in general, financial constraints,
913 regulatory barriers, and ageing infrastructure are the most common obstacles across all
914 regions. Internal organizational challenges are also likely to reinforce these barriers,
915 including siloed decision-making and budgeting, as described by several administrative
916 and academic respondents. In synthesising the insights on enabling factors, the analysis
917 suggests that successful initiatives in this study explicitly correlate in the data to two
918 specific institutional practices: First, the active involvement of stakeholders—students,

919 faculty, and staff—through dedicated programmes and governance committees that
920 survey respondents find associated with increased uptake of sustainability initiatives and
921 a more robust institutional culture of accountability. Second, the establishment of formal
922 monitoring and reporting frameworks for carbon emissions, which the case studies have
923 identified as an essential component for strategy evaluation, target setting, and
924 institutional accountability.

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

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

943 Overall, decarbonisation remains a complex and evolving process. It requires continuous
944 commitment, flexibility in the face of new challenges, and the capacity to adapt to

945 technological advancements and shifting sustainability paradigms. A long-term, strategic
946 vision, embedded within the university's core mission, strategy and institutional
947 planning, is essential for sustained progress and net zero carbon future.

948 **List of abbreviations**

949 AHP: Analytical Hierarchy Process
950 ASU: Arizona State University
951 BSI: British Standards Institution
952 CC: Climate Change
953 CF: Carbon Footprint
954 DEVE: European Parliament Committee on Development
955 DTU: Denmark Technical University
956 EEIO: Environmentally Extended Input-Output
957 EIO-LCA: Economic Input-Output – Life Cycle Assessment
958 GHG: Greenhouse Gas
959 GIA: Gross Internal Area
960 GPS: Global Positioning System
961 HEC: Higher Education Campus
962 HEI: Higher Education Institution
963 HFC: Hydrofluorocarbon
964 ICT: Information and Communication Technologies
965 ICP: Internal Carbon Pricing
966 IoT: Internet of Things
967 ISO: International Organization for Standardization
968 LCA: Life Cycle Assessment
969 NUS: National University of Singapore
970 PAS: Publicly Available Specification (standards, e.g. PAS 2050, PAS 2060)
971 PV: Photovoltaic
972 UC: University of California
973 UK: United Kingdom
974 UN: United Nations
975 US: United States

976 WBCSD: World Business Council for Sustainable Development

977 WRI: World Resources Institute

978 **Author's contributions**

979 WLF: conceptualization, methodology, writing—original draft, writing—review and
980 supervision. IE: paper management, editing and submission, writing—review, support
981 with data collection and processing. AOE: support with data collection and processing.
982 MME: support with data collection and processing. FMSA: support with data collection
983 and processing. MAPD: support with data collection and processing, writing—review.
984 JHE: support with data collection and processing. MM: support with data collection and
985 processing. JM: support with data collection and processing. AG: support with data
986 collection and processing, writing—original draft, writing—review. AK: paper
987 management and submission. YAA: paper management and submission, writing—review.
988 MV: support with data collection and processing. All authors reviewed the manuscript.

989 **Funding**

990 This research was supported by the Internal Faculty Start-Up Research Grant of
991 Wenzhou-Kean University Project No. ISRG2023014.

992 **Acknowledgement**

993 This work acknowledges the support of the Foundation for Science and Technology
994 within the framework of the UID/04292/MARE - Marine and Environmental Sciences
995 Centre.

996 **Data availability**

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

999 **Declarations**

1000 **Ethics and consent to participate**

1001 Informed consent was obtained from all individual participants included in the study.

1002 **Consent for publication**

1003 Not applicable.

1004 **Competing interests**

1005 The authors declare that they have no competing interests.

1006

1007 **References**

1008 Abu Qdais H, Saadeh O, Al-Widyan M, Al-tal R, Abu-Dalo M (2019) Environmental
1009 sustainability features in large university campuses: Jordan University of Science and

- 1010 Technology (JUST) as a model of green university. *Int J Sustain High Educ* 20(2):214–
1011 228.
- 1012 Adeyeye D, Olusola A, Orimoloye IR, Singh SK, Adelabu S (2023) Carbon footprint
1013 assessment and mitigation scenarios: A benchmark model for GHG indicator in a
1014 Nigerian University. *Environ Dev Sustain* 25(2):Article 2. doi:10.1007/s10668-021-
1015 02098-1.
- 1016 Agboola OS, Emmanuel M (2016) Awareness of climate change and sustainable
1017 development among undergraduates from two selected universities in Oyo State,
1018 Nigeria. *World J Educ* 6(3):70–81. <https://eric.ed.gov/?id=EJ1158351>. Accessed 19
1019 Sept 2025.
- 1020 Akbari H (2009) Cooling our communities. A guidebook on tree planting and light-colored
1021 surfacing. <https://api.semanticscholar.org/CorpusID:115739631>. Accessed 19 Sept
1022 2025.
- 1023 Anthony Jnr B (2021) Green campus paradigms for sustainability attainment in higher
1024 education institutions – a comparative study. *J Sci Technol Policy Manag* 12(1):117–
1025 148.
- 1026 Arizona State University (ASU) (2020) ASU Sustainability – Climate Positive 2019
1027 (published in 2010, updated in 2020). <https://cfo.asu.edu/climate-positive>. Accessed
1028 19 Sept 2025.
- 1029 Babbie E (2013) *The Practice of Social Research*. 13th ed, Wadsworth, Cengage Learning.
- 1030 Barron AR, Parker BJ, Sayre SS, Webers SS, Weisbord DJ (2020) Carbon pricing
1031 approaches for climate decisions in US higher education: Proxy carbon prices for deep
1032 decarbonization. *Elementa Sci Anthropocene* 8:42. doi:10.1525/elementa.443.
- 1033 Battistini R, Passarini F, Marrollo R, Lantieri C, Simone A, Vignali V (2023) How to assess
1034 the carbon footprint of a large university? The case study of University of Bologna’s
1035 multicampus organization. *Energies* 16(1):166.
- 1036 British Standards Institution (BSI) (2014) Carbon neutrality and PAS 2060.
1037 <https://www.bsigroup.com/en-GB/pas-2060-carbon-neutrality/>. Accessed 19 Sept
1038 2025.
- 1039 British Standards Institution (BSI) (2011) The guide to PAS 2050:2011 – How to carbon
1040 footprint your products, identify hotspots and reduce emissions in your supply chain.
1041 [https://www.bsigroup.com/globalassets/localfiles/en-th/carbon-footprint/pas-
1042 2050-2011-guide.pdf](https://www.bsigroup.com/globalassets/localfiles/en-th/carbon-footprint/pas-2050-2011-guide.pdf). Accessed 19 Sept 2025.
- 1043 Bueno G, de Blas M, Pérez-Iribarren E, Zuazo I, Torre-Pascual E, Erauskin A, Etxano I,
1044 Tamayo U, García M, Akizu-Gardoki O, León I, Marieta C, Zulueta G, Barrio I. (2021)
1045 The environmental and social footprint of the university of the Basque Country
1046 UPV/EHU. *J Clean Prod*, 315:128019.
- 1047 Bulunga AAL, Thondhlana G (2018) Action for increasing energy-saving behaviour in
1048 student residences at Rhodes University, South Africa. *Int J Sustain High Educ*
1049 19(4):773–789. doi:10.1108/IJSHE-07-2017-0107.

- 1050 Campos Guzmán V, Espinosa N, Cruz Guzmán V, Garcia-Cáscales S (2021) AHP-RIM to
1051 define the order of installation of photovoltaic systems in the creation of sustainable
1052 university campuses in Mexico. In: 25th International Congress on Project
1053 Management and Engineering, pp 1488–1500.
1054 [http://dspace.aepro.com/xmlui/bitstream/handle/123456789/2988/AT05-](http://dspace.aepro.com/xmlui/bitstream/handle/123456789/2988/AT05-004_21.pdf?sequence=1&isAllowed=y)
1055 [004_21.pdf?sequence=1&isAllowed=y](http://dspace.aepro.com/xmlui/bitstream/handle/123456789/2988/AT05-004_21.pdf?sequence=1&isAllowed=y). Accessed 19 Sept 2025.
- 1056 Cano N, Berrio L, Carvajal E, Arango S (2022) Assessing the carbon footprint of a
1057 Colombian university campus using the UNE-ISO 14064–1 and WRI/WBCSD GHG
1058 Protocol Corporate Standard. *Environ Sci Pollut Res*:1–17. doi:10.1007/s11356-022-
1059 22119-4.
- 1060 Clabeaux R, Carbajales-Dale M, Ladner D, Walker T (2020) Assessing the carbon footprint
1061 of a university campus using a life cycle assessment approach. *J Clean Prod*
1062 273:122600.
- 1063 Concordia University (2020) Sustainability Action Plan 2020–2025. Climate Action Plan.
1064 [https://www.concordia.ca/content/dam/concordia/services/sustainability/docs/H](https://www.concordia.ca/content/dam/concordia/services/sustainability/docs/Hub/plans/Climate-Plan.pdf)
1065 [ub/plans/Climate-Plan.pdf](https://www.concordia.ca/content/dam/concordia/services/sustainability/docs/Hub/plans/Climate-Plan.pdf). Accessed 19 Sept 2025.
- 1066 da Silva LA, de Aguiar Dutra AR, de Andrade Guerra JBSO (2023) Decarbonization in
1067 higher education institutions as a way to achieve a green campus: A literature review.
1068 *Sustainability* 15:4043. doi:10.3390/su15054043.
- 1069 Daglioglu ST (2021) Carbon footprint analysis of Ege University within the scope of
1070 environmental sustainability. *Commagene J Biol* 5(1):51–58.
- 1071 De Villiers C, Chen S, Jin C, Zhu Y (2014) Carbon sequestered in the trees on a university
1072 campus: a case study. *Sustain Account Manag Policy J* 5(2):149–171.
- 1073 Denmark Technical University (DTU) (2018) DTU Climate Strategy 2018–2023: Towards
1074 a carbon neutral campus in 2030 and beyond. [https://www.dtu.dk/english/news/all-](https://www.dtu.dk/english/news/all-news/nyhed?id=f7d51884-b52f-49e8-87ab-4f463beb73a4)
1075 [news/nyhed?id=f7d51884-b52f-49e8-87ab-4f463beb73a4](https://www.dtu.dk/english/news/all-news/nyhed?id=f7d51884-b52f-49e8-87ab-4f463beb73a4). Accessed 19 Sept 2025.
- 1076 El Geneidy S, Baumeister S, Govigli VM, Orfanidou T, Wallius V (2021) The carbon
1077 footprint of a knowledge organization and emission scenarios for a post-COVID-19
1078 world. *Environ Impact Assess Rev* 91:106645.
- 1079 Ellison B, Savchenko O, Nikolaus CJ, Duff BR (2019) Every plate counts: Evaluation of a
1080 food waste reduction campaign in a university dining hall. *Resour Conserv Recycl*
1081 144:276–284. doi:10.1016/j.resconrec.2019.01.046.
- 1082 Fissi S, Romolini A, Gori E, Contri M (2021) The path toward a sustainable green
1083 university: The case of the University of Florence. *J Clean Prod* 279:123655.
1084 doi:10.1016/j.jclepro.2020.123655.
- 1085 Franco D, Macke J, Cotton D, Paco A, Segers J-P, Franco L (2022a) Student energy-saving
1086 in higher education tackling the challenge of decarbonisation. *Int J Sustain High Educ*
1087 23(7):1648–1666. doi:10.1108/ijshe-10-2021-0432.
- 1088 Franco D, Segers JP, Herlaar R, Hannema AR (2022b) Trends in sustainable energy
1089 innovation: transition teams. *J Innov Manag* 10(2):22–46. doi:10.24840/2183-
1090 0606.010.002.0002

- 1091 The Greenhouse Gas Protocol (GHG) (2004) A corporate reporting and accounting
1092 standard. World Business Council for Sustainable Development, Geneva; World
1093 Resources Institute, Washington, DC.
- 1094 Gu Y, Wang H, Robinson ZP, Wang X, Wu J, Li X, Xu J, Li F (2018) Environmental footprint
1095 assessment of green campus from a food-water-energy nexus perspective. *Energy*
1096 *Procedia* 152:240–246.
- 1097 Gu Y, Wang H, Xu J, Wang Y, Wang X, Robinson ZP, Li F, Wu J, Tan J, Zhi X (2019)
1098 Quantification of interlinked environmental footprints on a sustainable university
1099 campus: A nexus analysis perspective. *Appl Energy* 246:65–76.
- 1100 Helmers E, Chang CC, Dauwels J (2021) Carbon footprinting of universities worldwide:
1101 Part I—objective comparison by standardized metrics. *Environ Sci Eur* 33:30.
1102 doi:10.1186/s12302-021-00454-6.
- 1103 Horan W, Shawe R, Moles R, O'Regan B (2019) Development and evaluation of a method
1104 to estimate the potential of decarbonisation technologies deployment at higher
1105 education campuses. *Sustain Cities Soc* 47:101464. doi:10.1016/j.scs.2019.101464.
- 1106 International Organization for Standardization (ISO) (2006) ISO 14064-1:2006,
1107 Greenhouse gases—Part 1: Specification with guidance at the organization level for
1108 quantification and reporting of greenhouse gas emissions and removals. Geneva.
1109 <https://www.iso.org/standard/38381.html>. Accessed 19 Sept 2025.
- 1110 International Organization for Standardization (ISO) (2018) ISO 14064-1, Greenhouse
1111 gases—Part 1: Specification with guidance at the organization level for quantification
1112 and reporting of greenhouse gas emissions and removals.
1113 <https://www.iso.org/standard/66453.html>. Accessed 19 Sept 2025.
- 1114 Kalkan N, Bercin K, Cangul O, Morales MG, Saleem MMKM, Marji I, Metaxa A, Tsigkogianni
1115 E (2011) A renewable energy solution for Highfield Campus of University of
1116 Southampton. *Renew Sustain Energy Rev* 15(6):2940–2959.
1117 doi:10.1016/j.rser.2011.02.040.
- 1118 Kasai N, Jabbour CJC (2014) Barriers to green buildings at two Brazilian engineering
1119 schools. *Int J Sustain Built Environ* 3(1):87–95. doi:10.1016/j.ijbsbe.2014.05.004.
- 1120 Kiehle J (2021) A carbon neutral campus: Tools of carbon footprint and handprint
1121 assessment. Master's thesis, University of Oulu.
1122 [https://oulurepo.oulu.fi/bitstream/handle/10024/17636/nbnfioulu-](https://oulurepo.oulu.fi/bitstream/handle/10024/17636/nbnfioulu-202105207984.pdf?sequence=1)
1123 [202105207984.pdf?sequence=1](https://oulurepo.oulu.fi/bitstream/handle/10024/17636/nbnfioulu-202105207984.pdf?sequence=1). Accessed 19 Sept 2025.
- 1124 Kiehle J, Kopsakangas-Savolainen M, Hilli M, Pongracz E (2023) Carbon footprint at
1125 institutions of higher education: The case of the University of Oulu. *J Environ Manag*
1126 329:117056. doi:10.1016/j.jenvman.2022.117056.
- 1127 Klaassen L, Stoll C (2021) Harmonizing corporate carbon footprints. *Nat Commun* 12(1).
1128 doi:10.1038/s41467-021-26349-x.
- 1129 Kourgiouzou V, Commin A, Dowson M, Rovas D, Mumovic D (2021) Scalable pathways to
1130 net zero carbon in the UK higher education sector: A systematic review of smart
1131 energy systems in university campuses. *Renew Sustain Energy Rev* 147:111234.
1132 doi:10.1016/j.rser.2021.111234.

- 1133 Kulkarni SD (2019) A bottom up approach to evaluate the carbon footprints of a higher
 1134 educational institute in India for sustainable existence. *J Clean Prod* 231:633–641.
 1135 doi:10.1016/j.jclepro.2019.05.194.
- 1136 Leal Filho W, Lange A, Frankenberger F, Akib NAM, Sen SK, Sivapalan S, Novo-Corti I,
 1137 Venkatesan M, Emblen-Perry K (2021) Governance and sustainable development at
 1138 higher education institutions. *Env Dev Sust* 23:6002-6020.
 1139 <https://doi.org/10.1007/s10668-020-00859-y>
- 1140 Leal Filho W, Vidal DG, Dinis MAP, Lambrechts W, Vasconcelos CRP, Molthan-Hill P,
 1141 Abubakar IR, Dunk RM, Salvia AL (2023a) Low carbon futures: assessing the status of
 1142 decarbonisation efforts at universities within a 2050 perspective. *Energy Sustain Soc*
 1143 13:5. doi:10.1186/s13705-023-00384-6.
- 1144 Leal Filho W, Yang P, Eustachio JHPP, Azul AM, Gellers JC, Gielczyk A, Dinis MAP, Kozlova
 1145 V (2023b) Deploying digitalisation and artificial intelligence in sustainable
 1146 development research. *Env Develop Sust* 25:4957–4988. doi:10.1007/s10668-022-
 1147 02252-3
- 1148 Leal Filho W, Eundeok K, Silva Borsatto JML, Bonato Marcolin C (2025) Using artificial
 1149 intelligence in sustainability teaching and learning. *Environ Sci Eu* 37:124.
 1150 doi:10.1186/s12302-025-01159-w
- 1151 Locatelli B, Aldunce P, Fallot A, Le Coq J-F, Sabourin E, Tapasco J (2017) Research on
 1152 climate change policies and rural development in Latin America: Scope and gaps.
 1153 *Sustainability* 9(10):1831. doi:10.3390/su9101831.
- 1154 Lozano R, Ceulemans K, Alonso-Almeida M, Huisingh D, Lozano FJ, Waas T, Lambrechts
 1155 W, Lukman R, Hugé J (2015) A review of commitment and implementation of
 1156 sustainable development in higher education: results from a worldwide survey. *J*
 1157 *Clean Prod* 108 (Part A): 1-18. doi: <https://doi.org/10.1016/j.jclepro.2014.09.048>
- 1158 Letete TCM, Mungwe NW, Guma M, Marquard A (2011) Carbon footprint of the University
 1159 of Cape Town. *J Energy South Afr* 22(2):2–12. doi:10.17159/2413-
 1160 3051/2011/v22i2a3208.
- 1161 Lund University (2019) Sustainability Forum. Lund University Sustainability Plan 2019–
 1162 2026: A roadmap for sustainable development at Lund University.
 1163 [https://www.staff.lu.se/sites/staff.lu.se/files/lund-universitys-strategy-for-](https://www.staff.lu.se/sites/staff.lu.se/files/lund-universitys-strategy-for-sustainable-development-2019-2026.pdf)
 1164 [sustainable-development-2019-2026.pdf](https://www.staff.lu.se/sites/staff.lu.se/files/lund-universitys-strategy-for-sustainable-development-2019-2026.pdf). Accessed 19 Sept 2025.
- 1165 Lund University (2021) Lund University's climate impact.
 1166 [https://www.sustainability.lu.se/sustainability-lu-2021/lund-universitys-climate-](https://www.sustainability.lu.se/sustainability-lu-2021/lund-universitys-climate-impact)
 1167 [impact](https://www.sustainability.lu.se/sustainability-lu-2021/lund-universitys-climate-impact). Accessed 19 Sept 2025.
- 1168 Lund University (2023) Sustainability plan for Lund University 2020–2026.
 1169 [https://www.lunduniversity.lu.se/sites/www.lunduniversity.lu.se/files/2024-](https://www.lunduniversity.lu.se/sites/www.lunduniversity.lu.se/files/2024-03/sustainability-plan-lund-university-2020-2026.pdf)
 1170 [03/sustainability-plan-lund-university-2020-2026.pdf](https://www.lunduniversity.lu.se/sites/www.lunduniversity.lu.se/files/2024-03/sustainability-plan-lund-university-2020-2026.pdf). Accessed 19 Sept 2025.
- 1171 Ma G, Shi W, Hou P (2023) Exploring university teacher construction for higher education
 1172 sustainability in China: Perspective from policy instruments. *Sustainability* 15(1):362.
 1173 doi:10.3390/su15010362.

- 1174 Maistry N, Annegarn H (2016) Using energy profiles to identify university energy
1175 reduction opportunities. *Int J Sustain High Educ* 17(2):188–207. doi:10.1108/IJSHE-
1176 09-2014-0129.
- 1177 Maistry N, McKay TM (2016) Promoting energy efficiency in a South African university. *J*
1178 *Energy South Afr* 27(3):1. doi:10.17159/2413-3051/2016/v27i3a1553.
- 1179 Mazhar M.U, Bull R, and Lemon M, (2017) Critical success factors for embedding carbon
1180 management in organizations: lessons from the UK higher education sector. *Carb*
1181 *Manag*, 8(5-6):379-392. Doi:10.1080/17583004.2017.1386533
- 1182 McCowan T (2020) The impact of universities on climate change: A theoretical
1183 framework. *Transforming Universities for a Changing Climate Working Paper Series*
1184 2:1–19.
1185 <https://www.academia.edu/download/64282439/Working%20paper,%20final.pdf>
1186 . Accessed 19 Sept 2025.
- 1187 McCowan T (2022) Can we measure universities' impact on climate change? *Int High Educ*
1188 111:17–19. <https://ejournals.bc.edu/index.php/ihe/article/view/15331>. Accessed
1189 19 Sept 2025.
- 1190 Mokski E, Leal Filho W, Sehnem S, Andrade Guerra JBSO (2023) Education for sustainable
1191 development in higher education institutions: An approach for effective
1192 interdisciplinarity. *Int J Sustain High Educ* 24(1):96–117. doi:10.1108/IJSHE-07-
1193 2021-0306.
- 1194 Monteiro S, Ribeiro V, Lemos K (2023) Sustainability reporting and the sustainable
1195 development goals in higher education: A Portuguese university case. In: *The*
1196 *complexities of sustainability*. World Scientific, pp 235–265.
1197 doi:10.1142/9789811258756_0008.
- 1198 Naderipour A, AbdulMalek Z, Arshad RN, Kamyab H, Chelliapan S, Ashokkumar V, Tavalaei
1199 J (2021) Assessment of carbon footprint from transportation, electricity, water, and
1200 waste generation: Towards utilisation of renewable energy source. *Clean Technol*
1201 *Environ Policy* 23:183–201. doi:10.1007/s10098-020-02017-4.
- 1202 National University of Singapore (2017) NUS Sustainability Strategic Plan 2017–2020 and
1203 Sustainability Roadmap 2030. <https://sustainability.nus.edu.sg/>. Accessed 19 Sept
1204 2025.
- 1205 Nottingham Trent University (2021) Carbon literacy training.
1206 [https://www.ntu.ac.uk/about-us/strategy/sustainability/sustainability-in-](https://www.ntu.ac.uk/about-us/strategy/sustainability/sustainability-in-curriculum/carbon-literacy-training)
1207 [curriculum/carbon-literacy-training](https://www.ntu.ac.uk/about-us/strategy/sustainability/sustainability-in-curriculum/carbon-literacy-training). Accessed 19 Sept 2025.
- 1208 Ogle KY, Hill J, Santen SA, Gottlieb M, Artino Jr AR (2023) Educator's blueprint: A how-to
1209 guide on survey administration. *AEM Educ Train* 7:e10906
- 1210 Pacca SA, Fonseca BM, Aguiar A de O e (2024) Commuting GHG emissions assessment for
1211 higher education institutions. 2024 International Conference on Resource
1212 Sustainability, Bangkok.
1213 <https://icrsconf.com/icRS/icRS%202024%20Abstract%20Book.pdf>. Accessed 19
1214 Sept 2025.

- 1215 Palanichamy C, Goh A (2016) Solar power for energy sustainability and environmental
1216 friendliness of Curtin University Sarawak. *IOP Conf Ser Mater Sci Eng* 121:012011.
- 1217 Park SI, Um JS (2018) Differentiating carbon sinks versus sources on a university campus
1218 using synergistic UAV NIR and visible signatures. *Environ Monit Assess* 190:652.
1219 doi:10.1007/s10661-018-7003-x.
- 1220 Quigley E, Bugden E, Odgers A (2020) Divestment: Advantages and disadvantages for the
1221 University of Cambridge. Cambridge, UK, pp 1–116.
1222 <https://ssrn.com/abstract=3849513>. Accessed 19 Sept 2025.
- 1223 Riddell W, Bhatia KK, Parisi M, Foote J, Imperatore J (2009) Assessing carbon dioxide
1224 emissions from energy use at a university. *Int J Sustain High Educ* 10(3):266–278.
- 1225 Robinson OJ, Tewkesbury A, Kemp S, Williams ID (2018) Towards a universal carbon
1226 footprint standard: A case study of carbon management at universities. *J Clean Prod*
1227 172:4435–4455.
- 1228 Rojas-Vargas J, Monge-Fernández Y, Fernández-Hidalgo K (2020) Desperdicios de
1229 alimentos (DA) en sodas concesionadas de una universidad pública en Heredia, Costa
1230 Rica. *Rev Tecnol Marcha*. doi:10.18845/tm.v33i1.5029.
- 1231 Samara F, Ibrahim S, Yousuf ME, Armour R (2022) Carbon footprint at a United Arab
1232 Emirates university: GHG protocol. *Sustainability* 14(5):2522.
- 1233 Sangwan KS, Bhakar V, Arora V, Solanki P (2018) Measuring carbon footprint of an Indian
1234 university using life cycle assessment. *Procedia* 69:475–480.
1235 doi:10.1016/j.procir.2017.11.111.
- 1236 Shulla K, Leal Filho W (2023) Achieving the UN Agenda 2030: Overall actions for the
1237 successful implementation of the Sustainable Development Goals before and after the
1238 2030 deadline. European Parliament.
1239 [https://www.europarl.europa.eu/thinktank/en/document/EXPO_IDA\(2022\)70257](https://www.europarl.europa.eu/thinktank/en/document/EXPO_IDA(2022)702576)
1240 6. Accessed 19 Sept 2025.
- 1241 Stein S (2023) Universities confronting climate change: Beyond sustainable development
1242 and solutionism. *High Educ*:1–19.
- 1243 Stenzel A, Waichman I (2023) Supply-chain data sharing for scope 3 emissions. *npj Clim*
1244 *Action* 2(1):7.
- 1245 The University of California (UC) (2013) UC Carbon Neutrality Initiative.
1246 <https://ucop.edu/carbon-neutrality-initiative/index.html>. Accessed 19 Sept 2025.
- 1247 The University of California (UC) (2023) UC Sustainable Practices Policy.
1248 <https://policy.ucop.edu/doc/3100155/SustainablePractices>. Accessed 19 Sept 2025.
- 1249 The University of Cambridge (2019) Zero Carbon.
1250 <https://www.cam.ac.uk/stories/cambridgezero>. Accessed 19 Sept 2025.
- 1251 The University of Edinburgh (2016) Zero by 2040: Sustainability and social responsibility
1252 strategy 2016–2020. [https://www.ed.ac.uk/sustainability/programmes-and-](https://www.ed.ac.uk/sustainability/programmes-and-projects/climate-strategy/zero-by-2040)
1253 [projects/climate-strategy/zero-by-2040](https://www.ed.ac.uk/sustainability/programmes-and-projects/climate-strategy/zero-by-2040). Accessed 19 Sept 2025.

- 1254 Tian X, Zhou Y, Morris B, You F (2022) Sustainable design of Cornell University campus
1255 energy systems toward climate neutrality and 100% renewables. *Renew Sustain*
1256 *Energy Rev* 161:112383.
- 1257 Timmons DS, Weil B (2021) A cost-minimizing approach to eliminating the primary
1258 sources of greenhouse gas emissions at institutions of higher education. *Int J Sustain*
1259 *High Educ* 23(3):604–621. doi:10.1108/ijshe-02-2021-0048.
- 1260 Torrijos V, Dopico DC, Soto M (2021) Integration of food waste composting and vegetable
1261 gardens in a university campus. *J Clean Prod* 315:128175.
1262 doi:10.1016/j.jclepro.2021.128175.
- 1263 Udas E, Wölk M, Wilmking M (2018) The “carbon-neutral university” – a study from
1264 Germany. *Int J Sustain High Educ* 19(1):130–145. doi:10.1108/IJSHE-05-2016-0089.
- 1265 Ullah I, Din Iud, Habiba U, Noreen U, Hussain M (2020) Carbon footprint as an
1266 environmental sustainability indicator for a higher education institution. *Int J Glob*
1267 *Warming* 20(4):277. doi:10.1504/IJGW.2020.107147.
- 1268 University of British Columbia (2021) Climate Action Plan 2030.
1269 https://planning.ubc.ca/sites/default/files/2021-12/UBCV_CAP2030_FINAL.pdf.
1270 Accessed 19 Sept 2025.
- 1271 Valls-Val K, Bovea MD (2021) Carbon footprint in higher education institutions: A
1272 literature review and prospects for future research. *Clean Techn Environ Policy*
1273 23:2523–2542. doi:10.1007/s10098-021-02180-2.
- 1274 Valls-Val K, Bovea MD (2022) Carbon footprint assessment tool for universities: CO2UNV.
1275 *Sustain Prod Consum* 29:791–804.
- 1276 Varón-Hoyos M, Osorio-Tejada J, Morales-Pinzón T (2021) Carbon footprint of a
1277 university campus from Colombia. *Carbon Manag* 12(1):93–107.
- 1278 Veludo G, Cunha M, Sá MM, Oliveira-Silva C (2021) Offsetting the impact of CO2 emissions
1279 resulting from the transport of Maiêutica’s academic campus community.
1280 *Sustainability* 13(18):Article 18. doi:10.3390/su131810227.
- 1281 Vrachni A, Christogerou A, Thomopoulos GA, Marazioti C, Angelopoulos GN (2022)
1282 Carbon footprint of the University of Patras in Greece: Evaluating environmental
1283 culture and campus’ energy management towards 2030. *Pollutants* 2:347–362.
1284 doi:10.3390/pollutants203002.
- 1285 Vásquez L, Iriarte A, Almeida M, Villalobos P (2015) Evaluation of greenhouse gas
1286 emissions and proposals for their reduction at a university campus in Chile. *J Clean*
1287 *Prod* 108:924–930. doi:10.1016/j.jclepro.2015.06.073.
- 1288 Whitfield K, Cretu A, Bousema T, Cohen J (2022) Environmentally sustainable practices in
1289 global health research and higher education institutions: Lessons from consultation
1290 with the TropEd Global Health institutions. *Trop Med Int Health* 27(2):122–128.
1291 doi:10.1111/tmi.13714.
- 1292 World Resources Institute; World Business Council for Sustainable Development (2013)
1293 Technical guidance for calculating Scope 3 emissions.

- 1294 https://ghgprotocol.org/sites/default/files/standards/Scope3_Calculation_Guidance_0.pdf. Accessed 19 Sept 2025.
1295
- 1296 Worsham M, Brecha RJ (2017) Carbon lock-in: An obstacle in higher education's
1297 decarbonization pathways. *J Environ Stud Sci* 7(3):435–449. doi:10.1007/s13412-
1298 017-0431-z.
- 1299 Yañez P, Sinha A, Vásquez M (2019) Carbon footprint estimation in a university campus:
1300 Evaluation and insights. *Sustainability* 12(1):1. doi:10.3390/su12010181.
- 1301 Yasuoka J, Cordeiro GA, Brittes JLP, Cooper Ordóñez RE, Bajay SV, Nunes E (2023) IoT
1302 solution for energy management and efficiency on a Brazilian university campus – a
1303 case study. *Int J Sustain High Educ* 24(2):426–448. doi:10.1108/IJSHE-08-2021-0354.
- 1304 Yin RK (2017) *Case study research and applications: Design and methods*, 6th edn. SAGE,
1305 Thousand Oaks. <https://us.sagepub.com/en-us/nam/case-study-research-and-applications/book250150>. Accessed 19 Sept 2025.
1306
- 1307 Zayit A, Song K, Ghengare AB, Gao F (2021) A study and assessment of the carbon footprint
1308 of Tianjin University's Weijin Road and Peiyangyuan campuses, China. *Research*
1309 *Square*. doi:10.21203/rs.3.rs-1021871/v1.
- 1310 Zhao W, Zou Y (2015) Green university initiatives in China: A case of Tsinghua University.
1311 *Int J Sustain High Educ* 16(4):491–506. doi:10.1108/IJSHE-02-2014-0021.
- 1312 Zheng N, Li S, Wang Y, Huang Y, Bartocci P, Fantozzi F, Li J (2021) Research on low-carbon
1313 campus based on ecological footprint evaluation and machine learning: A case study
1314 in China. *J Clean Prod* 323:129181.