Low carbon futures: assessing the status of decarbonisation efforts at universities within a 2050 perspective

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Abstract

Background The implementation of sustainability at universities means that they can also play a key role in the transition to a low carbon economy, and in assisting global efforts towards decarbonisation. Yet, not all of them have so far fully engaged in this area. This paper reviews the state of the art on trends in decarbonisation, and outlines the need for decarbonisation efforts at universities. It also reports on a survey aimed at ascertaining the extent to which universities in a sample of 40 countries across the various geographical regions are engaged in carbon reduction efforts, identifying the challenges faced.

Results The study has shown that the literature on the topic has been evolving over time and that increasing a given university's energy supply from renewable energy sources has been the cornerstone of university-based climate action plans. The study also indicates that even though several universities are concerned with their carbon footprint and actively seeking ways to reduce it, there are some institutional obstacles that need to be overcome.

Conclusions A first conclusion which can be drawn is that efforts on decarbonisation are becoming more popular, with a special focus being placed on the use of renewable energy. Also, the study has shown that, from the range of efforts being made towards decarbonisation, many universities are setting up a team with carbon management responsibilities, have Carbon Management Policy Statements, and review them. The paper points towards some measures which may be deployed, so as to allow universities to take better advantage of the many opportunities an engagement in decarbonisation initiatives offers to them.

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Background

Decarbonisation refers to the reduction of carbon. In terms of the global society, it refers to the creation of economies and systems that reduce the amount of carbon produced or emitted in an environmentally sustainable manner [1]. The significant increase in carbon dioxide emissions has contributed to climate change over recent years [2]. A consequence of increased carbon emissions is the rise of the global average temperature which has been recorded at its highest over the past two decades [3]. The Paris Climate Agreement was signed by many governments with the aim of reducing greenhouse gas emissions. This is essential to mitigate the effects of climate change. Anthropogenic activities contribute largely to carbon emissions and thus it is important for decarbonisation practices to be put into place [4].

Furthermore, climate change has caused the occurrence of extreme weather events including flooding, droughts, heatwaves, wildfires, erratic storms, and the rise in sea levels [5–8]. This has caused much concern among people who fear that climate change will worsen in the future. Aside from this, climate change is promoting and enhancing the spread of many diseases which places stress on human health [9]. Therefore, it is imperative for systems to be created with carbon-free goals.

The major contributor to carbon emissions is the burning of fossil fuels to produce energy [2]. The energy sector needs to shift towards alternative and 'clean' sources of power to ensure that decarbonisation is realised. This can be achieved by using renewable energy sources such as wind, solar or hydropower [10].

European countries have taken decarbonisation policies seriously and have incorporated methods into ensuring that they will be "fossil-free" by 2050. Policies are designed to ensure that decarbonisation occurs in electricity, transportation, buildings, heating, and industrial activity. For instance, the transportation sector in most countries contributes to a large amount of carbon dioxide emissions. This is referred to as energy-related carbon emissions and significantly contributes to climate change. Therefore, vehicles need to be designed to run on alternative sources of energy such as natural gas or hydroelectric power to ensure decarbonisation of the transport sector [11, 12]. The many needs in this field are being addressed using renewable energy sources and clean energy efficient technologies and practices [13] across a wide range of institutions, including at universities, as described in the next section of this paper.

Carbon reduction efforts at universities

Carbon management and reduction as a research topic have been explored in the higher education context in the past decades (e.g. [14, 15]). Following the approaches of ecological footprint analysis (EFA) and carbon footprint analysis (CFA) a number of Higher Education Institutions (HEIs) worldwide have been measuring their respective ecological footprints (EF) [16–18] and carbon footprint (CF) (e.g. [19–21]). The EF is broader in scope and approach, as it captures the impact, expressed in global hectares (gha), of several components, such as energy use; water use; waste; mobility; procurement; infrastructure; and food. The CF specifically sets focus on the amount of CO_2 emissions, expressed in tons (t) from different components. Three types of emissions are calculated: (1) ISO scope 1 emissions (direct emissions of the HEI, e.g. heating of buildings); ISO scope 2 (indirect emissions resulting from energy use); ISO scope 3 (other indirect emissions, e.g. resulting from commuting, procurement). Measuring the CF of universities is complex, and studies have shown that it is not feasible to compare results of CFA between different HEIs, due to differences in calculation methods used; interpretations of certain emission types; and (intentionally or unintentionally) excluding certain components, especially scope 3 emissions, from the calculation [22, 23].

Assessing the CFs of HEIs has several benefits. Having an exemplary function in society, universities can showcase how their daily operations contribute to societal sustainability transition, as has been outlined in several studies, e.g.: societal role, outreach [24, 25]; whole-school approach, practise what you preach [22]; campus as living laboratories [26, 27]. It is clear that attention towards CF analysis and -reduction has educational and societal benefits. Regarding campus operations, CF assessments ideally also result in future strategic interventions to reduce carbon emissions, e.g. through improving the built environment or investing in renewable energy [22, 28]. In a worldwide study, HEIs reported taking measures to reduce energy use, improve energy efficiency, and encourage renewable energy, as well as measures related to mobility, such as carbon offsetting and behavioural change of students and employees [29].

The majority of published articles present either (1) case studies of individual HEIs on CFA and CF reduction (e.g. [17, 20–22]; and/or (2) carbon management in higher education context (e.g. [15, 30, 31]. As a concept and practice, "decarbonisation" is yet hardly discussed in the current academic body of knowledge. The explicit mentioning of the term in relation to HEIs is scarce, and few studies refer to the potential of decarbonisation technologies at HEI campuses [32–34]. Apart from contributing to environmental, educational, and societal benefits, implementing decarbonisation efforts is believed to provide economic benefits for HEIs as well, although this is currently still being debated in the literature [14]. With constantly changing legislative boundary conditions, it is

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often difficult for HEIs to measure economic benefits in the short- and long-term [32].

A growing number of HEIs worldwide are committing to becoming carbon-neutral. In order to reach this goal, a variety of decarbonisation pathways have been described in the literature, which individual HEIs can apply and combine, such as: reducing energy consumption; renewable energy projects; carbon offsets; improving energy efficiency; power purchase agreements; open-market renewable energy certificates [35]. While many of the case studies present best practices, success factors, and strategies to reduce carbon emissions and improve carbon management (e.g. [30, 36], the uncertainties and risks associated with (long-term) decarbonisation decisions, such as carbon lock-in, are insufficiently addressed. Carbon lock-in refers to the process in which dominant (fossil fuel) technologies are still preferred over low carbon alternatives. Worsham and Brecha [36, p.436] refer to three types of carbon lock-in, that are mutually reinforcing: (1) infrastructural and technological carbon lock-in; (2) institutional carbon lock-in; (3) behavioural carbon lock-in. A lack of focus on these carbon lock-ins and associated risks comprises the risk that "higher education institutions unconsciously make decisions now that will hinder their abilities to meet their climate goals" in the future.

The term 'deep decarbonisation' refers to decarbonisation efforts that drastically aim to reduce carbon emissions and ultimately reach carbon neutrality [32, 37]. From a national policies perspective, three pillars of deep decarbonisation have been defined: "(i) energy efficiency and conservation, including structural and behavioural changes; (ii) decarbonisation of energy carriers (electricity, heat, liquids, and gases); and (iii) end-use switching to these low-carbon carriers" [38, p. 263]. These three pillars are also relevant within the HEI context, especially those oriented towards energy efficiency and decarbonisation of energy carriers. In order to reach carbon neutrality in HEIs, centralised measures are needed, also referred to as critical energy infrastructure decisions, such as installing carbon-neutral heating installations [32].

(Deep) decarbonisation in higher education can be seen as a way forward to the transition towards low-carbon futures. The COVID-19 pandemic forced HEIs worldwide to shift to digital ways of teaching, which directly affected the daily campus operations, related to mobility (students and employees commuting to the campus) as well as energy use [19]. However, effects of hybrid, online, or distance education have been studied earlier in relation to the CF of higher education (e.g. [38–40], the COVID-19 pandemic has led to a growing understanding of how such modes of distance learning might contribute to envisioning low carbon futures.

Methods

This study aimed to provide a greater understanding of the status of decarbonisation efforts that HEIs around the world contribute to by integrating climate solutions into their teaching, research, and operations activities, identifying the challenges they face within a 2050 perspective. To properly address the main objective of this research, a cross-sectional descriptive study was conducted, complemented by a survey. This type of dual study approach offers many advantages when it comes to shedding light on a given research topic, with the aim of fostering a greater understanding of new concepts or phenomena [41, 42].

The first step consisted of bibliometric analysis. Advances in text mining techniques have provided unprecedented opportunities to understand the overall structure and major focus areas of academic fields. For this purpose, different bibliometric analysis tools have been developed to identify influential sources, publications, and authors. Such tools can also be used to understand what thematic areas have received more attention. The latter is of interest to this study as it wants to find out what topics have received more attention in the literature related to university-based decarbonisation efforts. For this purpose, the study relies on the term co-occurrence analysis provided by VOSviewer, a frequently used bibliometric analysis technique [43]. The input data for term co-occurrence analysis are details of academic papers indexed in scientific databases. Here, the Web of Science (WoS), was used because of its broad coverage of peer-reviewed publications related to the study topic. To retrieve the relevant literature, a broad-based search was performed, which included a combination of different terms related to decarbonisation efforts at universities (see Appendix A). To develop the search string, an initial and simple combination of terms was used. However, after the initial search, it was also noticed that other terms, such as climate-neutral and carbon management, are also relevant and should be included. The final search was conducted on March 7, 2021, and returned 434 articles. The titles and abstracts of these articles were screened, and irrelevant papers were excluded. In the end, 116 papers were selected for final analysis using VOSviewer [44]. The output of term co-occurrence analysis is in a network of nodes and links, where node size is proportional to the term frequency and link width is proportional to the strength of the connection between two terms. Terms that are close to each other form thematic clusters that will be discussed in the "Results" section.

The second research method used in the second step was an online questionnaire. This was designed by a multidisciplinary team to be applied to students, researchers, educators, and administrative staff, to collect data

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regarding the decarbonisation efforts at HEIs. The questionnaire was designed based on previous literature which discusses decarbonisation issues [45–48].

The questionnaire, composed of 25 questions, was divided into 4 main parts: the first one aggregates 8 questions concerning participant background; the second part presents a set of 10 questions on the decarbonisation in campus operations to know if and how HEIs are performing actions and strategies; the third part, constituted of 4 questions, concerns decarbonisation in teaching and research and was designed to understand if this topic is incorporated in courses curriculum and teaching; the final part poses 3 questions to identify the main challenges and drives that HEIs are facing to implement decarbonisation strategies. The full questionnaire is presented in Appendix B. A pre-test was carried out by a group of academics whose fields of expertise lie within the scope of sustainable development research, to ensure that all relevant issues were considered and to check redundancies or similar items, as well as to evaluate the writing and sequence of questions. This process enables the questionnaire to be adjusted and redundant questions eliminated [49]. The language used was English.

The final version of the survey was administered through Google Forms and initially shared with scientific experts mailing lists and the network of the Inter-University Sustainable Development Research Programme (IUSDRP). A snowball sampling strategy was chosen to reach different viewpoints in a very small amount of time. Furthermore, in facing an emerging topic, such as decarbonisation, this sample allows us to reach the results faster and to provide up-to-date evidence [50]. The survey collected 110 responses between March and May 2021.

Results and discussion

This section was divided into two main parts. The first, relying on the bibliometric analysis, while the second was devoted to analysing the data collected from the survey.

Results of the bibliometric analysis

Four different thematic areas can be identified from the output of the term co-occurrence analysis that is shown using different colours (Fig. 1). In the blue cluster, 'carbon footprint' and 'sustainability' are two dominant terms indicating that university-based decarbonisation efforts are closely related and/or part of broader efforts aimed at creating sustainable universities [51, 52]. Such decarbonisation efforts have been developed and practised under different initiatives such as low-carbon campus [16, 53], green campus [54], climate-neutral

campus [52], and carbon-neutral university [55]. In these initiatives universities have functioned as living labs, practising a wide range of activities such as implementing innovative pilot projects [56], promoting sustainable behaviours among students [57], and examining the performance of universities as small-scale models of cities [58]. A common focus area of these campus-based efforts has been implementing renewable energy-based projects that are discussed under the red cluster. The blue cluster also includes terms 'mobility' and 'travel' that refers to issues related to reducing community- as well as long air travel-related emissions of students and faculty members [59, 60].

As mentioned above, increasing university energy supply from renewable energy sources has been the cornerstone of university-based climate action plans. This is evident in the red cluster, where terms such as 'renewable energy', and 'photovoltaics' are dominant. Obviously, of different renewable energy sources, solar energy has received more attention [61, 62]. The expansion of such renewable-energy-based initiatives is also expected to enhance efficiency by contributing to reducing energy loss in the distribution lines. It also facilitates the optimisation of energy management through, for instance, deploying microgrids that are integrated with renewable energy sources [63]. The economic feasibility of such systems has also been demonstrated through university-based pilot projects [64].

Energy-based initiatives in universities have also provided opportunities for enhancing student knowledge about renewable energy sources and technologies and this is also highlighted in the yellow cluster. Some universities have also integrated such subjects into the curriculum. This is believed to be important for further promotion and development of renewable energy technologies in the future [65]. Finally, the green cluster is dominated by terms such as 'climate change', and greenhouse gas (GHGs) that are linked with key terms related to management and governance. Clearly, effective management approaches are essential to ensure the success of university-based efforts towards decarbonisation [66]. Such management efforts should also be aware of the potential benefits of stakeholder engagement and community outreach for maximising performance through providing synergistic opportunities [67].

Results of the survey
Demographics
The first part of the survey aimed to know the respondents' profiles. In total 110 responses were collected from 40 countries, as listed in descending order of a number of responses by country: United States (9.1%), Canada
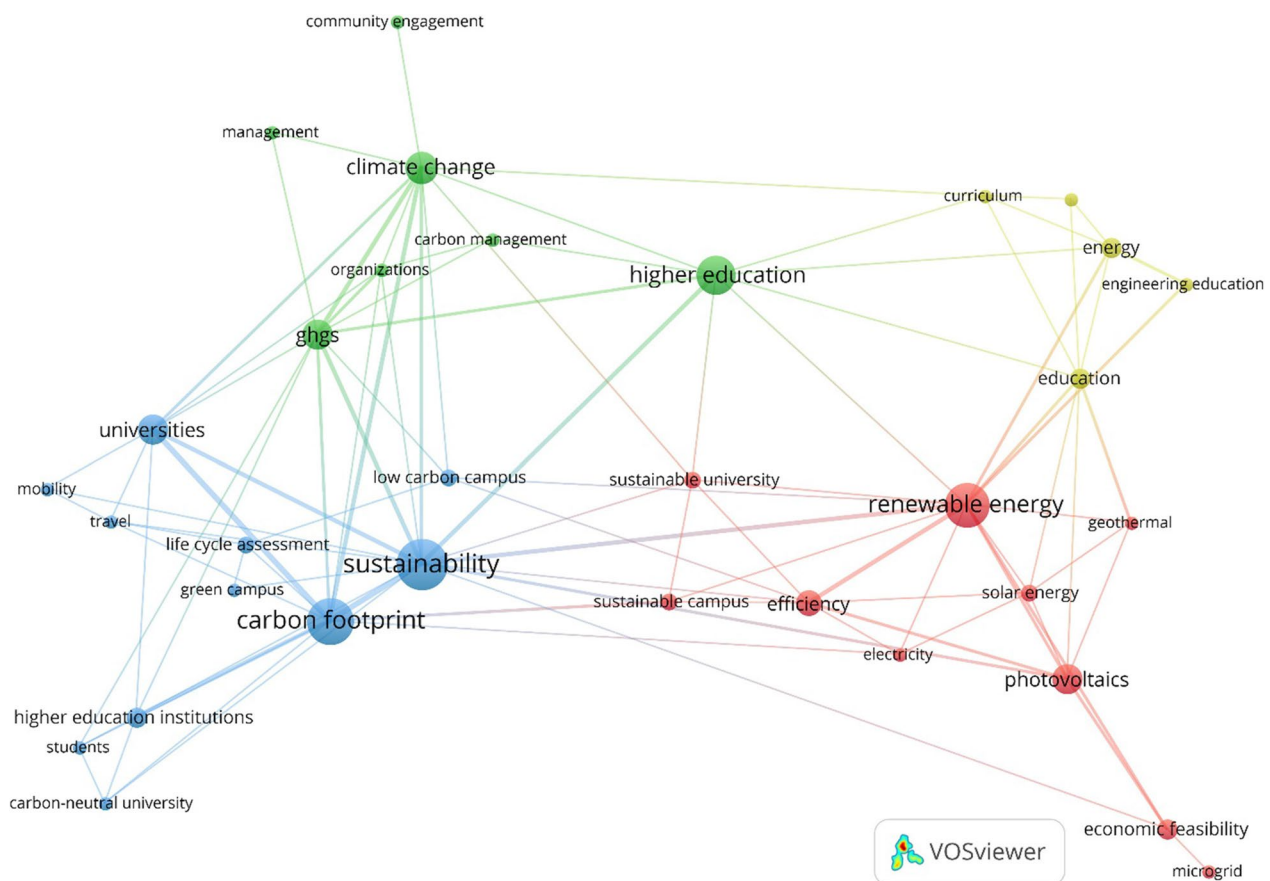
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Fig. 1 Output of the term co-occurrence analysis

(8.2%), Nigeria (8.2%), Saudi Arabia (7.3%), United Kingdom (7.3%), Brazil (6.4%), Portugal (5.5%), Australia (4.5%), Netherlands (3.6%), Japan, Kenya, Germany, Ghana, Greece, India, Iran, Mexico, Pakistan, Spain, Uganda, Bangladesh, Belgium, Bosnia, Colombia, Cote d'Ivoire, Croatia, Denmark, Estonia, Ethiopia, France, Italy, Kazakhstan, Malaysia, Malta, Mozambique, Philippines, Sweden, Switzerland, Taiwan, and Turkey The most representative countries had the percentage of respondents assigned in parenthesis. A map of the countries where the sampled respondents live is shown in Fig. 2. The socio-demographic characteristics of the sample are summarised in Table 1.

Prevailing in the sample are participants from Europe (30.0%) and Asia (20.9%), although the remaining continents are not imbalanced and there are no huge differences among them, allowing having an overview of the worldwide status of decarbonisation efforts at universities within a 2050 perspective. The majority are males (61.8%) and aged 33–47 years (47.3%), followed by those

aged 48–62 years (31.8%). Regarding the university classification, public universities were more participative in the study (79.1%) as well as postgraduate participants (90.0%). Lectures/professors (47.3%) and researchers (15.5%) represent the vast majority of the participants. They are mainly working in the field of social sciences (37.3%) and engineering and technology (22.7%).

Decarbonisation in campus operations
The second part of the survey addressed the topic of decarbonisation in campus operations. As will be detailed here, the results obtained on "Decarbonisation in campus operations" is mainly focused on energy efficiency and consumption reduction, as shown in Box 1. It highlights the internal efforts most addressed in low carbon policy in universities and in Box 2 that indicates the topics most addressed in decarbonisation campus operations. The results in Table 2 suggest that universities seem to be making an effort towards implementing a carbon management structure in HEIs.
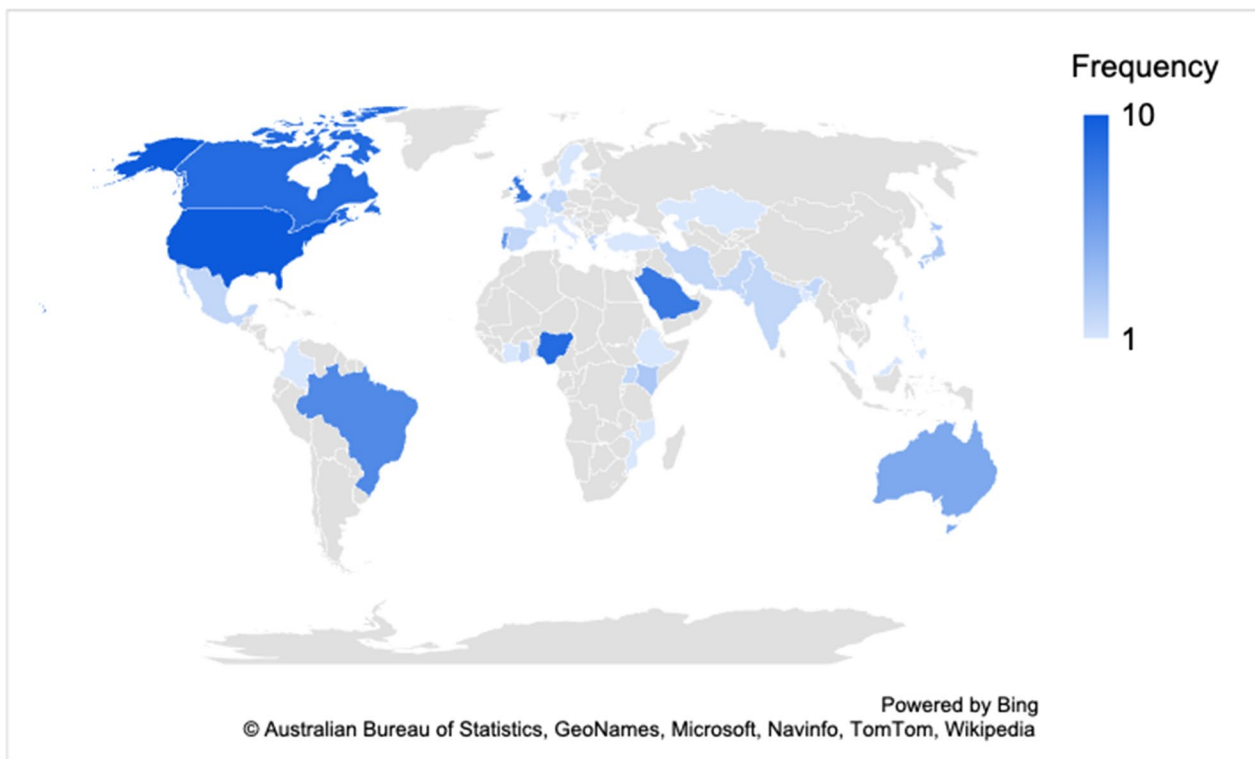
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Fig. 2 Country of the sampled respondents

However, in practice, when addressing specific questions (Fig. 3), those efforts are not that clear. 36.4% of the respondents (Fig. 4) state that their universities do produce or purchase part of their energy from renewable sources, which is a big step in the shift direction. That same focus is observed when analysing the responses towards trends in decarbonisation in the future, with 77.3% pointing out the need to increase renewable energy (Table 3). Both now and in the future (Table 3), carbon emissions reduction is emphasised by many (75.5% now and 70.9% in future 2050).

Regarding the type of sources used, 75.8% of respondents indicated solar energy as the primary source in response to the question regarding the most used sources to produce energy, followed by wind energy (28.6%), hydropower (25.3%), thermal energy (biomass) (12.1%) and geothermal energy (9.9%), with other sources being reported by a few cases.

In relation to the internal efforts pointed out to achieve progress in low carbon policy within the university, respondents gave a diversity of responses. However, the focus can be considered as pointing out to energy consumption reduction and improved efficiency, also highlighting the role of renewable energy and campus sustainability, as it is highlighted in Box 1.

Energy consumption reduction actions. Improved energy efficiency technology. Solar farms. Install photovoltaic plant. Campus sustainability (saving energy or planting trees). Renewable energy promotion. Zero carbon buildings. Climate Action Plan. Waste recycling. Awareness and sensitization. Management efforts.

Box 1. Topics highlighting the internal efforts most addressed in low carbon policy in universities

While these results are in line with a previous global review on sustainability integration in higher education (Lozano et al., 2015), it suggests that HEIs are struggling to take concrete measures towards carbon neutrality. However, some universities in our sample seem to have 'no structure in place for ensuring ongoing carbon management' (26.4%) or are 'not doing anything' (20.9%) as described in Table 2. Having only partially, or even not shifted to renewable sources, exemplifies that (deep) decarbonisation efforts are difficult to realise at universities. This might be under the influence of institutional carbon lock-ins (cf. [35]).

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Table 1 Socio-demographic characteristics of the respondents

Variable	Categories	Number ($n = 110$)	%
Region of your college/university	Africa	20	18.2
	Asia	23	20.9
	Europe	33	30.0
	North America	19	17.3
	South America	10	9.1
	Oceania	5	4.5
Gender	Male	68	61.8
	Female	37	33.6
	Other	1	0.9
	Prefer not to say	4	3.6
Age	18–32 yrs	15	13.6
	33–47	52	47.3
	48–62	35	31.8
	More than 63	8	7.3
University classification	Public	87	79.1
	Private	19	17.3
	Others (charity, philanthropic, foundation special status)	4	3.6
Highest education level	Secondary school or lower	1	0.9
	Tertiary education	10	9.1
	Postgraduate (e.g. MA/MSc, Ph. D.)	99	90.0
Primary position at the college/university	Lecturer/professor	52	47.3
	Researcher	17	15.5
	Student	12	10.9
	Administrative staff	15	13.6
	Higher management	11	10.0
	Sustainability education	1	0.9
	Researcher and lecturer	1	0.9
	Professor Emeritus	1	0.9
Main area of knowledge	Social sciences	41	37.3
	Engineering and technology	25	22.7
	Natural sciences	18	16.4
	Medical and health sciences	2	1.8
	Agricultural sciences	6	5.5
	Arts & humanities	5	4.5
	Sustainability and environmental studies	13	11.8

Table 2 Significant statements expressed by the respondents in relation to the carbon management structure adopted by the university

Most relevant responses	%
We have set up a team with carbon management responsibilities	36.4
We have a clear Carbon Management Policy Statement	34.5
We are set up to regularly review our carbon impact and revise our action plan	31.8
We have a defined person with carbon management responsibilities	30.9
We communicate the results of our carbon management progress to staff/customers	30.9
We have carried out a one-off 'Carbon Footprint & Recommendations' process	29.1
We currently have no structure in place for ensuring ongoing carbon management	26.4
We are not doing anything	20.9
When we are making decisions, we generally consider the carbon implications	19.1
We have implemented a permanent carbon management system	15.5
We are currently developing a carbon management programme	12.7

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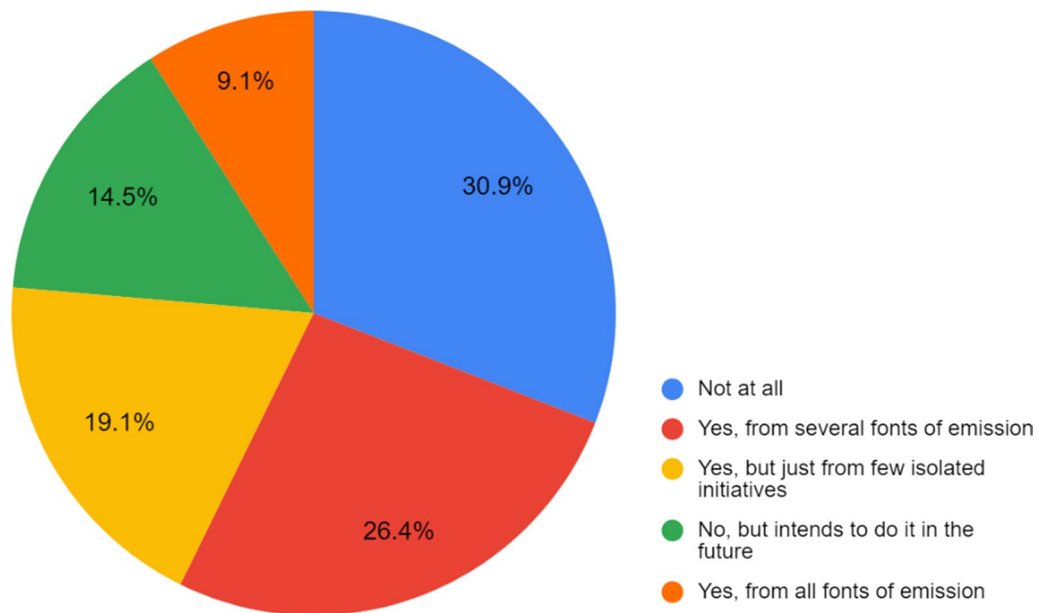
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Fig. 3 Assessing whether the university has a monitoring process to control emissions of greenhouse gases
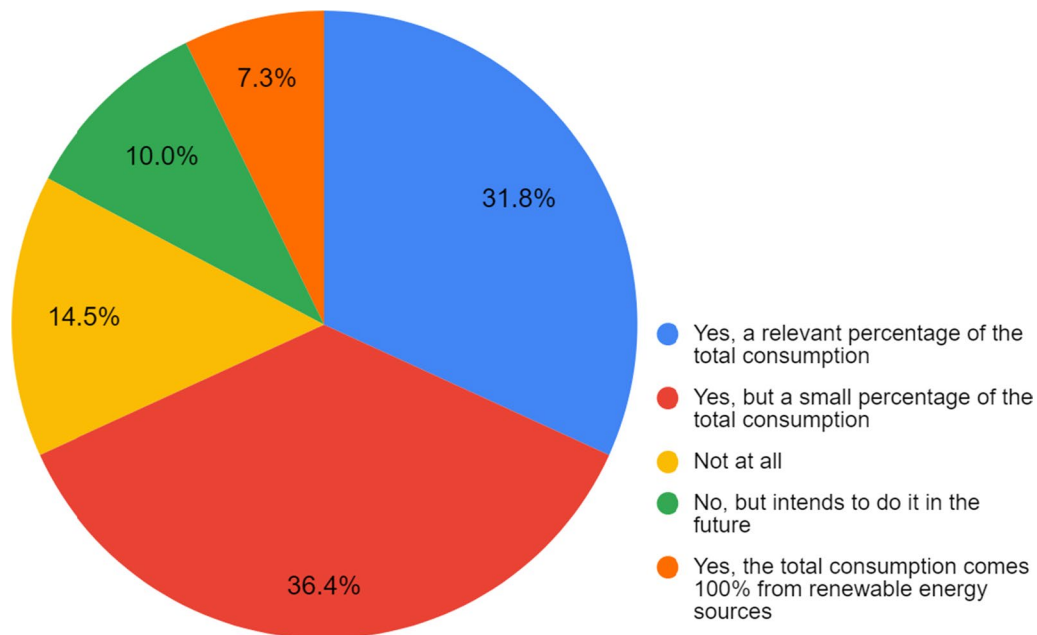

Fig. 4 Assessing whether the university produces or purchase part of its energy from renewable energy sources

In Table 3 is shown in the second column the trends of current topics and in the third one the trends of expected future topics that were considered more relevant to decarbonisation issues at HEIs.

In 7 out of the 10 trends most reported by respondents, it is shown that there is no expressive difference between

what is currently expected and what will be expected in the future, demonstrating the perception of urgency in addressing issues related to climate change by HEIs. It suggests the path that HEIs might follow to effectively contribute to achieving on-time what was established in the Paris Agreement. The results are in line with the

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Table 3 Most relevant statements expressed by the respondents about the important current trends and cross-cutting 2050 future expected trends involved in decarbonisation

Most relevant responses	Current trends (%)	Future expected trends (%)
Reduced carbon emissions	75.5	70.9
Increase the use of renewable energy	74.5	77.3
Promote energy efficiency	70.9	68.2
Increase social awareness and promote behaviour-change	67.3	66.4
More sustainable transportation	60.9	59.1
Energy and carbon literacy	53.6	57.3
Climate policy instruments	51.8	67.3
Levels of energy demand	49.1	50.0
Social or environmental justice	46.4	58.2
Technology support	39.1	–
Energy crisis, price, and policy	29.1	45.5

work of Leal Filho et al. [68], which aimed at identifying the extent to which matters related to climate change are addressed within the teaching and research practices at universities, with a focus on the training needs of teaching staff.

It is also noticed that statements more related to concrete aspects of campus operation that are usually in the scope of each HEI's internal decision-making, such as "Reduced carbon emissions", "Increase the use of renewable energy" or "Promote energy efficiency", were referred to more frequently by the sample of respondents. It may indicate that in the perception of them HEIs have been focused on carrying out actions of this type. In contrast, "Energy crisis, price and policy", "Social or environmental justice" and "Levels of energy demand" were marked by a smaller number of respondents possibly because they may perceive them as topics that are in the sphere of responsibility of governments and multilateral structures and therefore HEIs have little or no influence on those issues.

EU has embraced Europe to be a climate-neutral continent by 2050 [69]. That can only be achieved through the participatory involvement of all stakeholders and universities are crucial in this process, demanding further collaborative efforts in working together with industrial R&D departments [47, 69]. More than a set of goals, the energy transition journey in Europe will involve designing specific policies and measures [45]. Enquired whether the university had partnerships to design/implement a carbon-neutral plan, 44.5% of the respondents stated no partnership was developed with other stakeholders, followed by 24.5% of respondents that mentioned both city hall and companies/industry partnerships. NGOs were

mentioned by 16.4% of the respondents and civil society groups by 13.6%. Financial institutions corresponded to 6.4% and insurance companies to 3.6%. Universities and other organisations were mentioned by less than 1%. 1.8% of the respondents clearly mentioned no partnership at all.

Asked for additional comments on decarbonisation campus operations, some specific concerns were mentioned. The more reported comments are listed in Box 2.

> Energy efficiency.
> Green Hydrogen possibilities.
> Huge investment is needed to overcome fossil fuel.
> Carbon neutrality is the goal.
> Cross-understanding of initiatives and best practice monitoring approaches in universities.
> More communication in universities.
> Students or staff can take more actions to reduce emissions.
> The concept of decarbonisation has not yet sunk properly in the developing world.
> Awareness is still low.

Box 2. Topics most addressed in decarbonisation campus operations

Fossil-based energy is the main contributor to climate change, responsible for around 60% of global GHG emissions [70]. Countries intention to be virtually "fossil free" by 2050 [13]. Thus, efforts towards decarbonisation demand a holistic approach. In that respect, universities are considered to be a driving force in change, contributing to infrastructure development, technology improvement for cleaner and efficient energy globally, stimulating growth, and protecting the environment. In order to attain SDG 7 (affordable and clean energy) objectives to decarbonise the global energy system, all stakeholders are called to intervene. At the same time, decarbonising the energy system also impacts other SDGs, such as those addressing air pollution (SDGs 3 and 7), clean water (SDG 6), and food security (SDG 2) [71]. Low carbon economic strategies investment will support economic development in the future [72, 73].

The transport sector, representing a decarbonisation challenge due to carbon-intensive oil products used [74], accounts for more than 50% of total oil consumption [75] and universities seem to find it a relevant pathway towards decarbonisation efforts. Table 3 shows that sustainable transport is reported by almost 2/3 of the respondents (60.9%). Referring back to the EF literature, carbon emissions related to transport and mobility constitute a major part of the total emissions, yet are difficult to tackle from the organisational perspective [22]. For example, changing policies for internationalisation directly influences the research activities of faculty staff and might provoke resistance to such measures. A turnaway path in the political arena can be accomplished through fuel taxation (carbon tax/higher fuel prices) and

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emission standards, aiming to pursue energy efficiency and low emission.

Energy efficiency plays a major role in (deep) decarbonisation efforts [37]. While energy efficiency can be faced as the minimum energy to supply the same level of energy, the ecosystem-related approach goes one step further, aiming to safeguard the integrity of the ecosystem while simultaneously providing optimum energy services. Both views will ultimately aim to contribute to limiting human (GHG) emissions [70]. Scientists and researchers from universities are seen as reliable stakeholders in the energy efficiency field [48]. Accordingly, it is natural that this topic is considered to be important in the reported responses found in the analysis of the results (Box 1, Box 2 and Table 4), reflecting the fact that universities see energy efficiency efforts as a way to tackle 2050 decarbonisation efforts. The same exercise can be applied to the "Zero carbon buildings" goal, pointed out by the respondents (Box 1) in the scope of the efforts needed to be addressed by universities to achieve a low carbon policy. Global carbon targets cannot be attained without considering the buildings and universities represent that respect significant contributors, particularly those involving the technology areas, with experiments being carried out continuously, demanding additional energy effort. Clearly, energy topics addressed in the survey in the university context are all related to the sustainable pathway involved in efforts to progress towards a low carbon future. According to Donkor and Mearns [70], societies embracing sustainability will ultimately be the most successful and prosperous of the future and universities in particular, through research and also due to the important role played as stakeholders, are important players.

Waste recycling is mentioned in Box 1 as a topic to be addressed in the scope of low carbon policies and internal efforts. Low costs technology to control emissions from waste and wastewater handling and fossil fuel production and use are available through waste recycling and wastewater treatment plants [76] and further efforts in developing countries, those with the poorest management systems will significantly impact the reduction of global anthropogenic emissions in the 2050 timeframe, particularly methane.

Policy instruments are mentioned by 67.3% (Table 4) as important cross-cutting issues in relation to 2050 future trends in decarbonisation. However, they are unlikely to be realised without strong policy incentives, as advocated by Zhou et al. [77] when investigating low carbon investment needs involved in climate policy scenarios and we do know that universities tend to neglect specific aspects that could further be enhanced at this respect.

Education is essential in developing climate literacy at all levels of study and across all disciplines [78]. Communication, on the other hand, is highlighted in Box 2 as essential to decarbonisation efforts. Communication is essential [79] in the context of universities' actions to tackle decarbonisation efforts. The survey shows that energy and carbon literacy (53.6% in Table 4) in the context of universities represents an important trend in the decarbonisation topic, in agreement with what happens in the household context [48]. Awareness and sensitisation towards promoting behaviour change are important and highlighted through the results obtained in the survey, but it will also be crucial to persuade collective decision-making stakeholders to pursue that awareness, interest, and enthusiasm at the collective level [45]. Driving changes in behaviour could shape consumption habits, motivating further changes to emerge [46].

Biresselioglu et al. [45] found that barriers to European decarbonisation are frequently described as being confined to lower-level collective decision-making context, while the transition to low carbon is deemed inevitable for higher levels of governance, resulting in a strong will to overcome those barriers. The efforts to achieve decarbonisation at universities reported in this study seem to indicate that universities aim to play a relevant role in this respect. Several of the organisations which took part in this study seem to be interested in achieving campus sustainability, acting as living labs.

Table 4 Perception of the respondents regarding the integration of decarbonisation into teaching and research and its potential to engage students

	(a) Decarbonisation integrated into teaching (%)	(b) Decarbonisation integrated into research (%)	(c) Potential of decarbonisation themes to engage students (%)
Not at all	5	9	3
To a small extent	26	25	5
To some extent	40	34	25
To a moderate extent	19	16	27
To a great extent	9	16	40

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Decarbonisation in teaching and research/challenges and drivers

Table 4 presents the distribution of the sampled respondents in questions on how they perceive the integration of decarbonisation into teaching (a) and research (b), as well as the potential of decarbonisation themes to encourage students to be able to contribute to low carbon efforts at their institutions (c). It can be observed that factual elements (a, b) returned fewer positive responses, with more than half of the sample distributed among the mid-low response options (small/some extent). On the other hand, the normative element—potential to contribute—had over 90% of the sample distributed among the top three options (great/moderate/some extent). This finding indicates how the topic is perceived as important to mobilise students, even though it might have not been applied so satisfactorily in teaching and research.

After this set of questions, respondents were given an open space to comment on their views of decarbonisation in teaching and research. Table 5 presents these comments, classifying them among references to challenges, supporting arguments, and positive stories.

This study was also interested to investigate which are the main challenges and drivers for the implementation of decarbonisation initiatives at HEIs. The results

in Fig. 5 are presented as the percentage of respondents who indicated these aspects. When challenges are concerned, three in four respondents have indicated lack of funding as an important aspect to be considered. Lack of awareness of interest from staff and of material/resources are also among the most selected challenges (between 42 and 48%), reinforcing the need for effective management approaches [66]. On the other hand, the least voted challenge was lack of interest from students, indicated by only 16% of the sample. Other listed challenges include lack of governmental policies/support, problems in prioritisation, and distribution of funding.

As for drivers, four aspects were indicated by over 50% of the respondents: increased attractiveness to students (55%), benefits to the image of the organisation (55%), possibilities to reduce costs (58%), and sustainability culture among stakeholders (65%). The increased attractiveness to students can refer to the sustainability and climate action appeal, but also to the availability of on-campus initiatives to promote better learning opportunities and behaviour-change [26, 29]. Although controversial, the possibility of investments in decarbonisation for economic benefits is discussed in the literature [14] and the survey results confirmed this as an important supporting argument. A few other

Table 5 Open-space comments of the sample around the topic of decarbonisation in teaching and research

| Main topic	Quotes from respondents
Challenges	"Decarbonization remains predominantly technology focused, there is a need to better integrate social sciences and also to consider decarbonization from a systems level perspective versus one-off technologies" "Not enough courses are related to carbon emission reductions in the social science field"
	"Here, decarbonization is usually encountered as a theoretical issue in climate change research." "Too much curriculum is focused on all sources (including maintaining and making fossil more efficient), not picking & choosing future energy source winners. That doesn't prepare students to be leaders though."
	"It can and should be much more, but many teachers are not interested in the theme, researchers much more" "The curriculum is being 'greened' including around carbon emissions and climate change, but it is fragmented and not well coordinated."
Supporting arguments	"It is one concept that is gathering international attention, both in policymaking and academia, and worth embedding in teaching and research." "New research projects aligned to decarbonization are needed. An increase in inclusion, in curricular programmes" "The decarbonisation should be included in the curricula of the Universities" "We need more affirmative action""We need to learn more about this" "We should include it in all study plans""It's important to teach"
Positive stories	"I think many of our students come to us highly motivated about decarbonisation and other environmental protection. They fit with what many of our staff want to teach and research. Our campus has a high fraction of research and teaching concerned with renewables, ecology, geography, and sustainability."
	"Significant strengths" (e.g. centres/institutes on climate change/sustainable energy) "We are developing a new model on this topic" "We are launching a major effort" (referred to as a partnership for a centre on carbon capture)
	"We have an active focus on using campus operations as a classroom for students to learn about decarbonization" "We have embedded this in our teaching and research and more needs to be done across the schools" "We introduce the topic of decarbonization in our education in some of the courses, such as the one focusing on Closed Loop Supply Chains. Students have the option to choose for a master thesis topic on 'footprinting', which includes carbon or ecological footprinting." "Within our new plan is the target for all programmes at each level (first year, second year, etc.) to include the climate & ecological crisis in their indicative content"
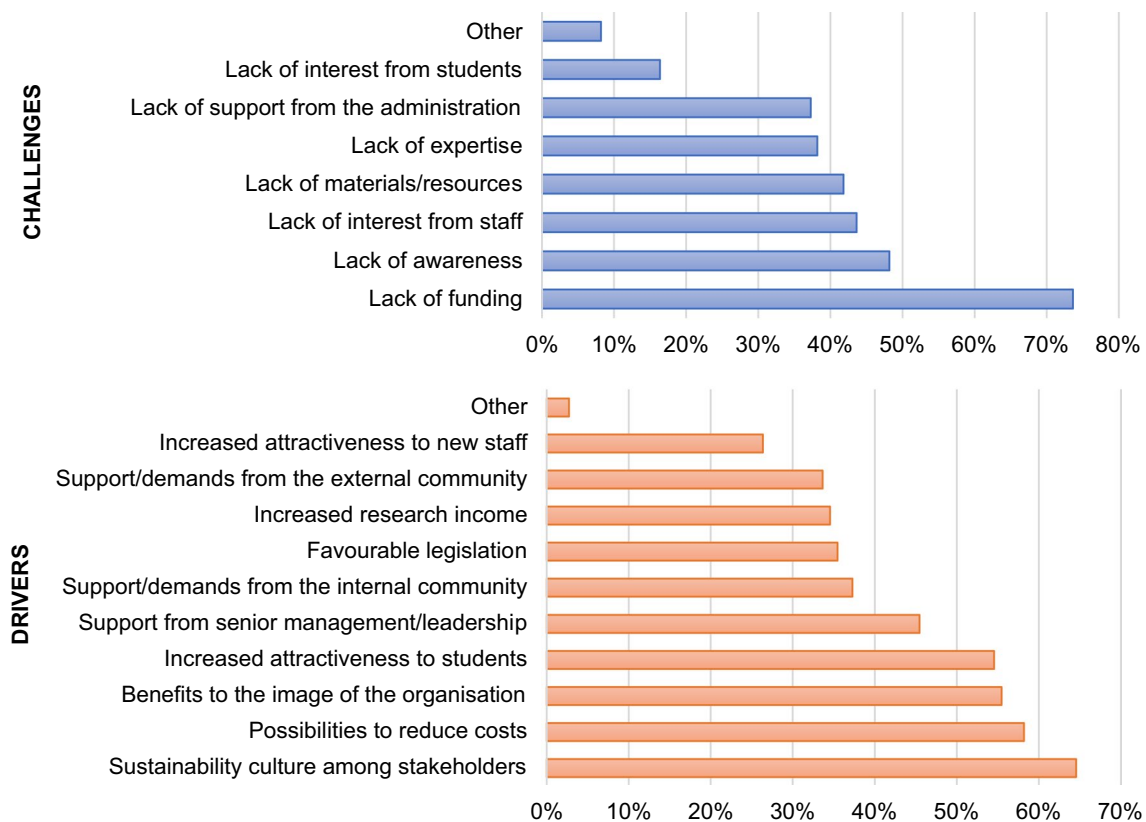
Fig. 5 Challenges and drivers for the implementation of decarbonisation initiatives at the sampled universities

examples of drivers were presented: interest of professors, researchers, and students, their active work in the area, and plan/policies from the external community (e.g. when a local council has a carbon zero plan).

It should be pointed out that there is a risk that some respondents may not be fully aware of the efforts being made at their universities to decarbonise. Despite this and considering the findings of this study, efforts should be expanded to increase the institutionalisation of sustainable development initiatives aimed at promoting decarbonisation in HEIs [80]. This may take place by developing clear policy statements, and carbon management systems. The institutionalisation and formalisation of action plans are considered in the literature as challenges that HEIs must overcome in order to adequately assume their role in building more sustainable societies [81, 82].

In this context, the engagement of the academic community is crucial in implementing sustainable development at HEIs and internalising it into the institutional culture [26, 83].

Conclusions

This article reports on a study focusing on decarbonisation at HEIs, which consisted of bibliometric analysis and an online survey taking place. A first conclusion which can be made is that efforts on decarbonisation are becoming more popular, with a special focus being placed on the use of renewable energy. Also, the study has shown that, from the range of efforts being made towards decarbonisation, many universities are setting up a team with carbon management responsibilities, have Carbon Management Policy Statements, and review them. Furthermore, over 75% of the respondents indicated solar energy as a primary source in their institutions. A reduction in carbon emissions is seen in most cases as a priority now and in the future, by a significant number of participants HEIs.

This study has some limitations. Firstly, it relied on the term co-occurrence analysis provided by VOSviewer. Even though this is a frequently used bibliometric analysis technique, it has a constraint in respect of the number of terms that can be assessed.

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Secondly, the online questionnaire survey was undertaken over a short period of time and could only involve HEIs staff who were motivated—and interested to take part in it. Thirdly, the size of the sample, which involved 110 respondents, cannot be regarded as representative, although relating 40 countries.

Despite these limitations, the paper makes a timely contribution to the literature in the sense that it provides a profile of the extent to which universities are engaging in decarbonisation efforts. Also, the sample, which entails respondents from 40 countries, illustrates the levels of emphasis the topic is currently having. The sample also fulfils the purpose of outlining some of the challenges that HEIs currently face in reducing their CF.

Some of the measures which may be deployed, so as to allow universities to take better advantage of the many opportunities an engagement in decarbonisation initiatives offers to them are:

(a) to promote wider awareness of the fact that decarbonisation is not a sole task for the university administration, but that it is a goal also to be embraced by staff and students;
(b) themes associated with decarbonisation such as CO_2 emissions or the use of renewable energy, may be used as part of a wide range of courses, raising the awareness of students across the social and natural sciences, and not only in engineering, as it is sometimes the case;
(c) efforts to foster decarbonisation may be supported by the use of digitalisation, with tools that enable more resource and energy efficiency, and better network utilisation and new technologies that may contribute to climate protection;
(d) research at the interfaces of decarbonisation and overall climate protection efforts should be promoted more strongly.

In addition, bearing in mind the high demand for skilled workers in the field of climate protection, knowledge of matters related to decarbonisation may be helpful in meeting with the shortages of personnel in the labour market. This trend, in turn, gives an opportunity for universities to strengthen their further education programmes. Overall, in order to better tap the potentials of decarbonisation, greater emphasis should be given to giving universities incentives to better integrate decarbonisation as part of their transformation process.

Appendix A: Search string

(TS= (("carbon neutral*" OR "climate action" OR "climate change in the curriculum" OR "climate mitigation" OR "climate change mitigation" OR "decarboni*" OR "carbon literacy" OR "renewable energy*" OR "zero carbon" OR "low carbon" OR "zero-carbon" OR "low-carbon" OR "net zero" OR "climate neutral" OR "climate-neutral" OR "NZEB" OR "carbon management" OR "carbon efficiency" OR "carbon footprint") NEAR/15 ("universit*" OR "higher education institut*"))) *AND* **LANGUAGE:** (English)

Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=1900-2021

Appendix B: Survey

1. Country of your college/university:

_____

4. Gender

( ) Female, ( ) Male, ( ) Other, ( )Prefer not to say.

5. Age, (numerical – e.g., 32):

_____

6. Highest Educational Level:

( ) Secondary school or lower; ( ) Tertiary education; ( ) Postgraduate (e.g., MA/MSc, Ph. D.)

7. Primary position at the college/university:

( ) Student; ( ) Researcher; ( ) Lecturer/Professor; ( ) Administrative Staff; ( ) Higher management; ( ) Other_____

8. Which is your main area of knowledge:

( ) Natural Sciences; ( ) Engineering and technology; ( ) Medical and Health sciences; ( ) Agricultural sciences; ( ) Social sciences; ( ) Arts & Humanities; ( ) Other: _____

9. At the best of your knowledge, please mark the statements related to the carbon management structure adopted by your college/university.

( ) We have a clear Carbon Management Policy Statement; ( ) We have a defined person with carbon management responsibilities; ( ) We have set up a team with carbon management responsibilities; ( ) We have carried out a one-off 'Carbon Footprint & Recommendations' process; ( ) We are set up to regularly review our carbon impact & revise our Action Plan; ( ) We communicate the results of our carbon management progress to staff/customers; ( ) We have implemented a permanent Carbon Management System; ( ) We currently have no structure in place for ensuring ongoing carbon management; ( ) We are currently developing a Carbon Management programme; ( ) When we are making decisions we generally

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consider the carbon implications; ( ) We are not doing anything; ( ) Other: _____

10. Does your university have a monitoring process to control its emissions of greenhouse gases?

( ) Not at all; ( )No, but intends to do it in the future; ( ) Yes, but just from few isolated initiatives; ( ) Yes, from several fonts of emission; ( )Yes, from all fonts of emission.

11. Does your university produce/purchase part of its energy from renewable energy sources?

( ) Not at all; ( )No, but intends to do it in the future; ( )Yes, but a small percentage of the total consumption; ( )Yes, a relevant percentage of the total consumption; ( ) Yes, the total consumption comes 100% from renewable energy sources.

11.1 If so, which sources are used? (Multiple answer possible)

( )Hydropower; ( ) Solar energy; ( ) Wind energy; ( ) Thermal energy (biomass); ( ) Geothermal energy; ( ) Other: _____

12. Which internal efforts can you point out within your college/university context to achieve progress in low carbon policy? _____

_____

13. In your opinion, important current trends in decarbonisation involve which of the following topics? (Multiple choices possible)

( ) Levels of energy demand Increase use of renewable energy; ( )Promote energy efficiency; ( ) Reduced carbon emissions; ( )Energy crisis, price, and policy; ( )Climate policy instruments; ( ) Increase social awareness and promote behaviour-change; ( )Energy and carbon literacy; ( ) More sustainable transportation; ( ) Technology support; ( ) Social or environmental justice; Other:_____

14. In your opinion, 2050 future expected trends in decarbonisation involve which of the following cross-cutting issues? (Multiple choices possible)

( ) Levels of energy demand; ( ) Increase use of renewable energy; ( ) Promote energy efficiency; ( ) Reduced carbon emissions; ( ) Energy crisis, price and policy; ( ) Climate policy instruments; ( ) Increase social awareness and promote behaviour-change; ( ) Energy and carbon literacy; ( ) More sustainable transportation; ( ) Social or environmental justice; Other: _____

15. Has your college/university partnered with other stakeholders to design/implement their carbon neutral plan? If so, with which partners? (Multiple choices possible)

( )It has not developed the plan/partnered with other stakeholders; ( ) City Hall; ( ) Insurance companies; ( ) Companies/Industry; ( ) Financial institutions; ( ) Civil society groups; ( ) NGOs; Other: _____

16. Please, use this space If you would like to make any comments regarding decarbonisation in campus operations

_____

17. To the best of your knowledge, is the topic of decarbonisation integrated into any teaching programs at your college/university?

( ) Not at all; ( ) To a small extent; ( ) To some extent; ( ) To a moderate extent; ( ) To a great extent

18. To the best of your knowledge, are your college/university involved in researching decarbonisation?

( ) Not at all; ( ) To a small extent; ( ) To some extent; ( ) To a moderate extent; ( ) To a great extent

19. Do you believe that decarbonisation themes have the potential to encourage students to be able to contribute to low carbon efforts at your college/university?

( ) Not at all; ( ) To a small extent; ( ) To some extent; ( ) To a moderate extent; ( ) To a great extent

20. Please, use this space If you would like to make any comments regarding decarbonisation in teaching and research

Challenges and drivers

21. Which elements pose a challenge to the efforts of implementing decarbonisation initiatives at your college/university? (Multiple answers possible)

( )Lack of expertise; ( ) Lack of awareness; ( ) Lack of interest from staff; ( ) Lack of interest from students; ( ) Lack of materials/resources; ( ) Lack of support from the administration; ( ) Lack of funding; Other: _____

22. Which elements represent drivers for the implementation of decarbonisation initiatives at your college/university? (Multiple answers possible)

( ) Sustainability culture among stakeholders; ( ) Favourable legislation; ( ) Benefits to the image of the organization; ( ) Possibilities to reduce costs; ( ) Increased attractiveness to students; ( ) Increased attractiveness to new staff; ( ) Increased research income; ( ) Support from senior management/leadership; ( ) Support/demands from the internal community; ( ) Support/demands from the external community; Other: _____

23. If you have specific examples of a case study or project involving decarbonisation at your university, briefly describe the experience (objective, method, impact, and results, for example).

Author contributions
WLF was responsible for the article's concept and contribute with the whole manuscript; RMD, IRA and PM-H wrote the literature review of the manuscript;

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DGV, AS and CRPV wrote the method section; MAPD, WL, ALS, AS and CRPV wrote the results and discussion. All authors read and approved the final manuscript.

Declarations

Ethical approval and consent to participate
Informed consent was obtained on the web survey from all individual participants included in the study. The data collected do not allow the individual identification of the participant.

Consent for publication
Not applicable.

Competing interests
The authors declares that they have no competing interests.

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References

1. Capros P, Paroussos L, Fragkos P et al (2014) Description of models and scenarios used to assess European decarbonisation pathways. Energy Strateg Rev 2:220–230
2. Cavicchioli R, Ripple WJ, Timmis KN et al (2019) Scientists' warning to humanity: microorganisms and climate change. Nat Rev Microbiol 17:569–586
3. Arguez A, Hurley S, Inamdar A et al (2020) Should we expect each year in the next decade (2019–28) to be ranked among the top 10 warmest years globally? Bull Am Meteorol Soc 101:E655–E663
4. Gössling S, Scott D (2018) The decarbonisation impasse: global tourism leaders' views on climate change mitigation. J Sustain Tour 26:2071–2086. https://doi.org/10.1080/09669582.2018.1529770
5. Mann ME, Rahmstorf S, Kornhuber K et al (2017) Influence of anthropogenic climate change on planetary wave resonance and extreme weather events. Sci Rep 7:45242
6. Mukherjee S, Mishra A, Trenberth KE (2018) Climate change and drought: a perspective on drought indices. Curr Clim Chang Reports. 4:145–163. https://doi.org/10.1007/s40641-018-0098-x
7. Bevacqua E, Maraun D, Vousdoukas MI et al (2019) Higher probability of compound flooding from precipitation and storm surge in Europe under anthropogenic climate change. Sci Adv 5:eaaw5531. https://doi.org/10.1126/sciadv.aaw5531
8. Williams AP, Abatzoglou JT, Gershunov A et al (2019) Observed impacts of anthropogenic climate change on wildfire in California. Earth's Futur 7:892–910. https://doi.org/10.1029/2019EF001210
9. Ogden N, Gachon P (2019) Climate change and infectious diseases: what can we expect? Canada Commun Dis Rep. 45:76–80
10. Papadis E, Tsatsaronis G (2020) Challenges in the decarbonization of the energy sector. Energy 205:118025
11. Sovacool BK (2007) Solving the oil independence problem: is it possible? Energy Policy 35:5505–5514
12. Sovacool BK, Noel L, Kester J et al (2018) Reviewing Nordic transport challenges and climate policy priorities: expert perceptions of decarbonisation in Denmark, Finland, Iceland, Norway, Sweden. Energy 165:532–542
13. Sovacool BK (2017) Contestation, contingency, and justice in the Nordic low-carbon energy transition. Energy Policy 102:569–582
14. Li Z, Chen Z, Yang N et al (2021) Trends in research on the carbon footprint of higher education: a bibliometric analysis (2010–2019). J Clean Prod 289:125642
15. Robinson O, Kemp S, Williams I (2015) Carbon management at universities: a reality check. J Clean Prod 106:109–118
16. Liu H, Wang X, Yang J et al (2017) The ecological footprint evaluation of low carbon campuses based on life cycle assessment: a case study of Tianjin, China. J Clean Prod 144:266–278
17. Genta C, Favaro S, Sonetti G et al (2019) Envisioning green solutions for reducing the ecological footprint of a university campus. Int J Sustain High Educ 20:423–440. https://doi.org/10.1108/IJSHE-01-2019-0039/full/html
18. Ortegon K, Acosta P (2019) Ecological footprint: a tool for environmental management in educational institutions. Int J Sustain High Educ 20:675–690. https://doi.org/10.1108/IJSHE-09-2018-0156/full/html
19. Filimonau V, Archer D, Bellamy L et al (2021) The carbon footprint of a UK University during the COVID-19 lockdown. Sci Total Environ 756:143964
20. Larsen HN, Pettersen J, Solli C et al (2013) Investigating the carbon footprint of a university—the case of NTNU. J Clean Prod 48:39–47
21. Ozawa-Meida L, Brockway P, Letten K et al (2013) Measuring carbon performance in a UK University through a consumption-based carbon footprint: De Montfort University case study. J Clean Prod 56:185–198
22. Lambrechts W, Van Liedekerke L (2014) Using ecological footprint analysis in higher education: campus operations, policy development and educational purposes. Ecol Indic 45:402–406
23. Robinson OJ, Tewkesbury A, Kemp S et al (2018) Towards a universal carbon footprint standard: a case study of carbon management at universities. J Clean Prod 172:4435–4455
24. Evans J, Karvonen A (2014) 'Give me a laboratory and I will lower your carbon footprint!'—urban laboratories and the governance of low-carbon futures. Int J Urban Reg Res 38:413–430. https://doi.org/10.1111/1468-2427.12077
25. Genus A, Theobald K (2015) Roles for university researchers in urban sustainability initiatives: the {UK} Newcastle Low Carbon Neighbourhoods project. J Clean Prod 106:119–126
26. Leal Filho W, Salvia AL, Pretorius RW, et al. Universities as living labs for sustainable development: supporting the implementation of the sustainable development goals. World Sustain Ser. 2020.
27. Save P, TerimCavka B, Froese T (2021) Evaluation and lessons learned from a campus as a living lab program to promote sustainable practices. Sustainability 13:1739
28. Alghamdi A, Haider H, Hewage K et al (2019) Inter-university sustainability benchmarking for Canadian higher education institutions:

water, energy, and carbon flows for technical-level decision-making. Sustain 11:2599

29. Lozano R, Ceulemans K, Alonso-Almeida M et al (2015) A review of commitment and implementation of sustainable development in higher education: results from a worldwide survey. J Clean Prod 108:1–18

30. Mazhar MU, Bull R, Lemon M (2017) Critical success factors for embedding carbon management in organizations: lessons from the UK higher education sector. Carbon Manag. 8:379–392. https://doi.org/10.1080/17583004.2017.1386533

31. Mazhar MU, Bull R, Lemon M, et al. Carbon management planning in UK Universities: a journey to low carbon built environment. Univ Initiat Clim Chang Mitig Adapt. Cham: Springer International Publishing; 2019. p. 33–56. https://doi.org/10.1007/978-3-319-89590-1_3.

32. Barron AR, Parker BJ, Sayre SS, et al. Carbon pricing approaches for climate decisions in U.S. higher education: proxy carbon prices for deep decarbonization. In: Kapuscinski AR, Frumhoff PC, editors. Elem Sci Anthr. 2020;8. https://doi.org/10.1525/elementa.443/114479/Carbon-pricing-approaches-for-climate-decisions-in.

33. Horan W, Shawe R, Moles R et al (2019) Development and evaluation of a method to estimate the potential of decarbonisation technologies deployment at higher education campuses. Sustain Cities Soc 47:101464

34. Victor DG, Abdulla A, Auston D et al (2018) Turning Paris into reality at the University of California. Nat Clim Chang 8:183–185

35. Worsham M, Brecha RJ (2017) Carbon lock-in: an obstacle in higher education's decarbonization pathways. J Environ Stud Sci 7:435–449. https://doi.org/10.1007/s13412-017-0431-z

36. Button CE (2009) Towards carbon neutrality and environmental sustainability at CCSU. Int J Sustain High Educ 10:279–286. https://doi.org/10.1108/14676370910972585/full/html

37. Waisman H, Bataille C, Winkler H et al (2019) A pathway design framework for national low greenhouse gas emission development strategies. Nat Clim Chang 9:261–268

38. Caird S, Lane A, Swithenby E et al (2015) Design of higher education teaching models and carbon impacts. Int J Sustain High Educ 16:96–111. https://doi.org/10.1108/IJSHE-06-2013-0065/full/html

39. Roy R, Potter S, Yarrow K (2008) Designing low carbon higher education systems. Int J Sustain High Educ 9:116–130. https://doi.org/10.1108/14676370810856279/full/html

40. Versteijlen M, Perez Salgado F, Janssen Groesbeek M et al (2017) Pros and cons of online education as a measure to reduce carbon emissions in higher education in the Netherlands. Curr Opin Environ Sustain 28:80–89. https://doi.org/10.1016/j.cosust.2017.09.004

41. Grimes DA, Schulz KF (2002) Descriptive studies: what they can and cannot do. Lancet 359:145–149

42. Tarzian AJ, Cohen MZ (2011) Descriptive research. In: Fitzpatrick JJ, Kazer M (eds) Encycl Nurs Res, 3rd edn. Springer Publishing Company, Berlin, p 732

43. van Eck NJ, Waltman L (2010) Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84:523–538. https://doi.org/10.1007/s11192-009-0146-3

44. Eck NJ van, Waltman L. VOSviewer Manual: Manual for VOSviewer version 1.6.16. 2020.

45. Biresselioglu ME, Demir MH, Demirbag Kaplan M et al (2020) Individuals, collectives, and energy transition: analysing the motivators and barriers of European decarbonisation. Energy Res Soc Sci 66:101493

46. Dubois G, Sovacool B, Aall C et al (2019) It starts at home? Climate policies targeting household consumption and behavioral decisions are key to low-carbon futures. Energy Res Soc Sci 52:144–158

47. OECD/IEA/NEA/ITF. Aligning Policies for a Low-carbon Economy. Paris, France: OECD Publishing; 2015.

48. Sovacool BK, Cabeza LF, Pisello AL et al (2021) Decarbonizing household heating: reviewing demographics, geography and low-carbon practices and preferences in five European countries. Renew Sustain Energy Rev 139:110703

49. Hilton CE (2017) The importance of pretesting questionnaires: a field research example of cognitive pretesting the Exercise referral Quality of Life Scale (ER-QLS). Int J Soc Res Methodol 20:21–34

50. Bornstein MH, Jager J, Putnick DL (2013) Sampling in developmental science: situations, shortcomings, solutions, and standards. Dev Rev 33:357–370

51. Yoshida Y, Shimoda Y, Ohashi T (2017) Strategies for a sustainable campus in Osaka University. Energy Build 147:1–8

52. Opel O, Strodel N, Werner KF et al (2017) Climate-neutral and sustainable campus Leuphana University of Lueneburg. Energy 141:2628–2639

53. Na W, Zhao ZC. The comprehensive evaluation method of low-carbon campus based on analytic hierarchy process and weights of entropy. Environ Dev Sustain. 2020.

54. Ridhosari B, Rahman A (2020) Carbon footprint assessment at Universitas Pertamina from the scope of electricity, transportation, and waste generation: toward a green campus and promotion of environmental sustainability. J Clean Prod 246:119172

55. Udas E, Wölk M, Wilmking M (2018) The, "carbon-neutral university"—a study from Germany. Int J Sustain High Educ 19:130–145

56. Bouscayrol A, Castex E, Delarue P, et al. Campus of university with mobility based on innovation and carbon neutral. In: 2017 IEEE Veh Power Propuls Conf VPPC 2017 Proc. 2018. p. 1–5.

57. Li X, Tan H, Rackes A (2015) Carbon footprint analysis of student behavior for a sustainable university campus in China. J Clean Prod 106:97–108

58. Guerrieri M, La Gennusa M, Peri G et al (2019) University campuses as small-scale models of cities: quantitative assessment of a low carbon transition path. Renew Sustain Energy Rev 113:109263

59. Davies JC, Dunk RM (2016) Flying along the supply chain: accounting for emissions from student air travel in the higher education sector. Carbon Manag. 6:233–246. https://doi.org/10.1080/17583004.2016.1151503

60. Sultana S, Kim H, Pourebrahim N et al (2018) Geographical assessment of low-carbon transportation modes: a case study from a commuter university. Sustain 10:2696

61. D'Adamo I, de Monte F, Ferella F et al (2021) The case study of a photovoltaic plant located at the university of L'Aquila: an economic analysis. J Clean Prod 278:123561

62. Hernandez-Escobedo Q, Ramirez-Jimenez A, Dorador-Gonzalez JM, et al. Sustainable solar energy in Mexican Universities. Case Study: The National School of Higher Studies Juriquilla (UNAM). Sustain. 2020.

63. Shirzadi N, Nasiri F, Eicker U. Optimal configuration and sizing of an integrated renewable energy system for isolated and grid-connected microgrids: the case of an Urban University Campus. Energies. 2020.

64. Vu BH, Husein M, Kang H-K et al (2019) Optimal design for a campus microgrid considering ESS discharging incentive and financial feasibility. J Electr Eng Technol 14:1095–1107

65. Wang X, Guo L. How to promote university students to innovative use renewable energy? An inquiry-based learning course model. Sustain. 2021.

66. Wade B, Griffiths A (2020) Examining best practice carbon management within Australian organisations: cases from contrasting sectors. Australas J Environ Manag 27:156–172

67. Linda T, Bhishna B (2015) Sustainable campus: engaging the community in sustainability. Int J Sustain High Educ 16:57–71

68. Leal Filho W, Sima M, Sharifi A et al (2021) Handling climate change education at universities: an overview. Environ Sci Eur 33:109

69. Peters D, van der Leun K, Terlouw W, et al. Gas Decarbonisation Pathways 2020–2050—Gas for Climate. Utrecht; 2020. Available from: https://gasforclimate2050.eu/sdm_downloads/2020-gas-decarbonisation-pathways-study/.

70. Donkor FK, Mearns K. Clean energy solutions and sustainable development. 2021; 144–152. https://doi.org/10.1007/978-3-319-95864-4_123.

71. Zhou W, McCollum DL, Fricko O et al (2020) Decarbonization pathways and energy investment needs for developing Asia in line with 'well below' 2 °C. Clim Policy. 20:234–245. https://doi.org/10.1080/14693062.2020.1722606

72. Schandl H, Hatfield-Dodds S, Wiedmann T et al (2016) Decoupling global environmental pressure and economic growth: scenarios for energy use, materials use and carbon emissions. J Clean Prod 132:45–56

73. Leal Filho W, Yang P, Eustachio JHPP et al (2022) Deploying digitalisation and artificial intelligence in sustainable development research. Environ Dev Sustain. https://doi.org/10.1007/s10668-022-02252-3

74. Mulholland E, Teter J, Cazzola P et al (2018) The long haul towards decarbonising road freight—a global assessment to 2050. Appl Energy 216:678–693

75. Yan S, de Bruin K, Dennehy E et al (2021) Climate policies for freight transport: energy and emission projections through 2050. Transp Policy 107:11–23

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76. Höglund-Isaksson L, Gómez-Sanabria A, Klimont Z et al (2020) Technical potentials and costs for reducing global anthropogenic methane emissions in the 2050 timeframe—results from the GAINS model. Environ Res Commun. 2:025004. https://doi.org/10.1088/2515-7620/ab7457

77. Zhou W, McCollum DL, Fricko O et al (2019) A comparison of low carbon investment needs between China and Europe in stringent climate policy scenarios. Environ Res Lett 14:054017. https://doi.org/10.1088/1748-9326/ab0dd8

78. Molthan-Hill P, Robinson ZP, Hope A et al (2020) Reducing carbon emissions in business through responsible management education: influence at the micro-, meso- and macro-levels. Int J Manag Educ. 18:100328

79. Leal Filho W, Morgan EA, Godoy ES et al (2018) Implementing climate change research at universities: barriers, potential and actions. J Clean Prod 170:269–277

80. Leal Filho W, Vidal DG, Chen C, et al. An assessment of requirements in investments, new technologies and infrastructures to achieve the SDGs. Environ Sci Eur. 2022.

81. Hernández-Diaz PM, Polanco J-A, Escobar-Sierra M et al (2021) Holistic integration of sustainability at universities: evidences from Colombia. J Clean Prod 305:127145

82. Leal Filho W, Shiel C, Paço A (2016) Implementing and operationalising integrative approaches to sustainability in higher education: the role of project-oriented learning. J Clean Prod 133:126–135. https://doi.org/10.1016/j.jclepro.2016.05.079

83. Vasconcelos CRP, Ferreira P, Araújo M, et al. Students' perception of campus sustainability in a Brazilian University. Univ Sustain Soc Support Implement Sustain Dev Goals. Springer Berlin/Heidelberg; 2021. p. 285–304. https://doi.org/10.1007/978-3-030-63399-8_19.

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