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Sustainable Development in Third Level Programs: Distilling a Pathway to a True Net-Zero Education

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Abstract: This study probes the notable gap between the theoretical endorsement of the UN Sustainable Development Goals (SDGs), particularly SDGs 7, 12, and 13, and their tangible implementation in higher education curricula. We hypothesize that entrenched unsustainable practices in key academic disciplines, such as engineering and business, persist despite the global shift towards sustainability. The study engages a diverse cohort of participants from academia, public, private, and nonprofit sectors, chosen for their distinct roles and insights in integrating SDGs into educational and industrial frameworks. Our research design integrates an extensive qualitative literature review and critical analyses with quantitative surveys using specially designed instruments. The study was conducted with a sample of 48 participants, representing various sectors, using specially designed survey instruments to gauge expert opinions on the barriers and opportunities in advancing sustainable education. Our findings identify economic and administrative hurdles as primary impediments to academia's shift towards sustainability. The data underscore the urgent need for targeted strategies in transitioning to a net-zero educational paradigm. The study concludes with a call to reshape academic initiatives, highlighting the critical role of education in preparing future leaders. It emphasizes bridging the gap between theoretical support for SDGs and their practical application in academia, proposing actionable strategies for this alignment.

Keywords: academic decarbonization; clean energy transition; net-zero education; sustainable development goals; student engagement in sustainability

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Citation: Al Kez, D.; Lowans, C.; Foley, A. Sustainable Development in Third Level Programs: Distilling a Pathway to a True Net-Zero Education. *Sustainability* **2024**, *16*, 1998. https://doi.org/10.3390/su16051998

Academic Editors: Oz Sahin and Russell Richards

Received: 7 December 2023
Revised: 23 January 2024
Accepted: 1 February 2024
Published: 28 February 2024

1. Introduction

Universities and other higher education institutions have the potential to contribute to solving challenges such as climate change, but the extent to which this is happening in practice is unclear and difficult to measure [1]. These institutions play a key role in the reduction of unsustainability, but they also have the resources and influence to redirect their activities towards progressive social and ecological ends [2]. The acknowledgment of the crucial role that universities play in forming leaders, decision-makers, and educators in society underscores their significance in influencing sustainability both at national and local levels [3]. However, influencing universities to prioritize social and ecological protection requires changes in academic practices, including research, education, outreach, and engagement [4]. Additionally, universities need to bridge the attitude–behavior gap in students' climate-related actions through climate change education (CCE) which includes enhancing students' knowledge, practical skills, and community engagement [5].

Decarbonization from a university perspective appears to consider only the physical environment (i.e., mostly Scope 1 and 2 emissions), with only occasional consideration of Scope 3 emissions. For example, there is a growing recognition of the importance of integrating scientific waste approaches and circular economy principles to reduce CO_2 emissions on university campuses [6]. The University of Exeter has primarily focused on reducing Scope 1 and 2 emissions [7], but this approach may not be sufficient, as Scope 3 emissions can make up a significant portion of a university's carbon footprint [8]. Concerns also extend to the hidden curriculum of sustainability in higher education and the visibility of climate change issues on campus [9]. Here, 'curriculum' refers to the set of subjects within the course curricula. To enhance the meaningful incorporation of sustainability in education, a proposed approach involves integrating its components into curricula, programs, and subjects across all levels of the education system through infusion or integration [10]. Thus far, there has been very little consideration of issues such as universities' roles in promoting climate justice, and equity, or the content of their curricula [11]. Indeed, it is noted that universities which turn from this paradigm to another may be best placed to deliver lasting public value [12], particularly in the area of social impact [13].

In this context, 'decarbonization of pedagogy in higher education' refers to the deliberate and systematic efforts to reduce carbon emissions associated with educational practices within universities. It encompasses a comprehensive approach that goes beyond the traditional focus on physical environmental aspects, such as Scope 1 and 2 emissions, to include a broader consideration of the ecological impact of academic activities, including research, teaching, and outreach. The goal is to align educational practices with sustainability principles, emphasizing a shift toward cleaner energy sources, responsible consumption and production, and active climate action, as outlined in the United Nations Sustainable Development Goals (SDGs), particularly SDG 7.

The incorporation of the UN SDGs into academic research and pedagogy has been widely welcomed. However, progress in implementing these goals, especially SDGs 7 (Affordable and Clean Energy), 12 (Responsible Consumption and Production), and 13 (Climate Action), has been relatively limited across various disciplines, including engineering, sciences, law, economics, and business. Despite the enthusiastic reception, there is still a predominant focus on unsustainable fossil fuel industries within these disciplines, posing a challenge to the effective integration of the SDGs into academic practice [14]. The selection of SDGs 7, 12, and 13 as the focal points of our study is intentional, guided by their direct relevance to the core functions of universities and their potential to catalyze transformative change within academic institutions. SDG 7 aligns with the imperative for clean energy, crucial for reducing carbon emissions and promoting sustainability within higher education [15]. SDG 12 emphasizes responsible consumption and production, addressing the need for sustainable practices within academic institutions [16]. Lastly, SDG 13 focuses specifically on climate action, aligning with the overarching theme of decarbonization in higher education.

In the quest to bridge the gap between theoretical knowledge and actionable steps toward achieving the SDGs, overcoming this lack of action would benefit not only academia but also society and industry, which are increasingly prioritizing environmental, social, and governance issues. Indeed, some university courses are beginning to incorporate some elements of the SDGs in their teaching, but this is limited so far [17]. The initial state of knowledge and commitment of students towards the SDGs is not as widespread as expected. A study conducted at the Polytechnic University of Valencia (UPV) found that while students have some knowledge about the SDGs, they lack understanding of their role and the responsible parties involved in achieving the goals [18]. Another study at Universiti Teknologi MARA (UiTM) revealed that only a portion of the university curriculum addresses the SDGs, with three goals not being addressed at all [19]. The need for educational resources to teach the concept of the SDGs is also highlighted, with Design Based Learning (DBL) being identified as a potential approach [20].

Contrary to previous research, this study aims to examine the opportunities and barriers to overcoming this inertia via a mixed methods approach of literature review, expert survey, and critique. This research adds to the existing knowledge base by identifying key barriers and opportunities for accelerating clean energy transition in academic pedagogy through an extensive literature review. While this work serves as a foundational step, it is inherently limited by space constraints, intending to guide future research by prioritizing and directing efforts within each identified barrier category. Although our primary audience is WEIRD countries (Western, Educated, Industrialized, Rich, and Democratic), we aspire to broaden this scope in future research endeavors (Figure 1).

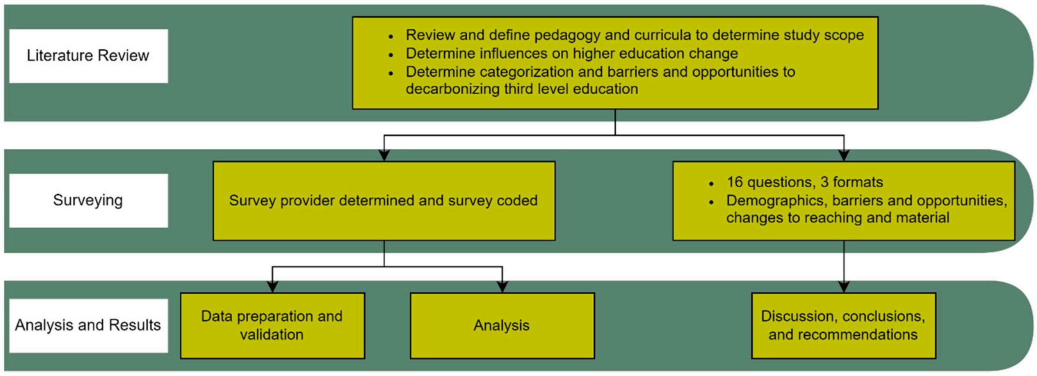

Figure 1. Research process flow diagram (source: authors).

2. Background

Pedagogy is defined as the "art, science or profession of teaching", intricately tied to the teaching–learning process. It refers to the methods and strategies used in teaching and educating individuals, particularly in the field of formal education [21]. While pedagogy encompasses the broader spectrum of teaching as both an art and science, it is crucial to acknowledge that the effectiveness of the teaching–learning process relies on appropriate didactic strategies based on established theories and principles of science teaching [22].

Pedagogy serves as the "instructional technology" guiding the practical application of education to influence learning outcomes. It embodies the interactive connections between learning, teaching, and culture [23]. Innovative pedagogies provide a comprehensive and inclusive understanding of pedagogy in the 21st century, as they involve constant research and adaptation to meet the needs of an ever-changing society [24]. These pedagogies embrace diverse outcomes and are collaboratively negotiated and pursued as integral components of the teaching process, in contrast to convergent approaches that adhere to precise planning [25]. In higher education institutions, innovative pedagogies such as flipped classrooms, SCALE-UP, and blended teaching and learning have been found to be effective, sustainable, and student-centered [26]. However, mobile pedagogy, particularly in the context of distance education, exhibits regional variations in both theory and practice, with little divergence from the traditional educational system [27].

Pedagogical practices are the means teachers use to inspire learning and guide intellectual and personal development [28]. They encompass the theories, principles, and practices of teaching and learning, and involve the design, implementation, and evaluation of educational programs and curricula. Pedagogy also encompasses the roles and responsibilities of teachers and instructors, as well as how they interact with their students, including feedback and assessment and creating learning environments [29]. It is a continuous process that changes and adapts to new knowledge, technology, and society's needs, serving as a link connecting principles with practical implementation.

Viewing pedagogy as being at the intersection of theory and practice, the OECD's recent assessment highlighted six clusters of innovative pedagogies, as shown in Figure 2 [30]. These pedagogical clusters serve a dual purpose: (i) they act as a matrix for categorizing teaching approaches and recognizing overarching pedagogical methods, and (ii) they maintain a level of flexibility, translating learning principles into specific teaching practices in order to achieve new learning objectives without succumbing to predetermined prescriptions [23].

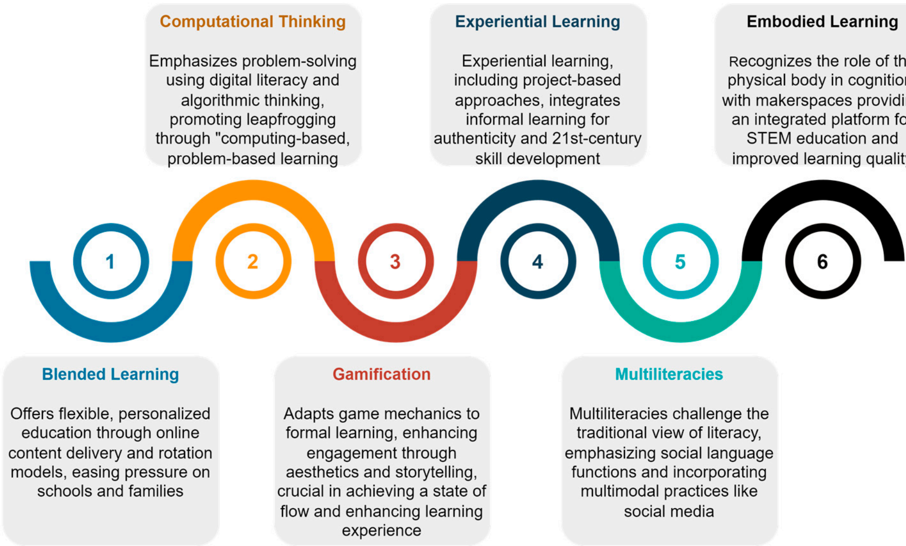

Figure 2. Six innovative pedagogy clusters.

Furthermore, to address the climate crises, the education system must undergo a process of decarbonization by integrating sustainability principles and transformative approaches. This transformative journey involves developing new ways of living that align with the complex nature of socioecological crises [31]. Higher education can play a pivotal role in this transformation by fostering key competencies such as practical wisdom, providing a robust framework for education guided by sustainability principles [32].

It is important to move from a primary focus on personal happiness and attainment to a more balanced interest in human flourishing within the context of sustainable and regenerative futures [33]. In terms of learning outcomes, the emphasis would be on knowledge, skills, values, and attitudes, rather than specifically virtues [34]. Education should strive to be holistic, transformative, and learner-centered, emphasizing learning over metrics [35]. To effectively evaluate sustainability education, new forms of assessment are needed. The role of education in shaping values, mindsets, and ethical behaviors for caring and responsible societies is crucial.

In the UK, the University and College Union (UCU) defines decarbonizing the education system as "Decarbonising our education system means transforming how and what we learn so that education sufficiently addresses and prepares students for the climate crisis and ecological emergency. That means our curricula must equip students with the knowledge, skills, attitudes, and values to tackle the reformation of our currently carbon-intense economic system. Furthermore, it means thinking critically and challenging the influence of corporations like fossil fuel companies in our research, funding, and sponsorship" [36]. The UCU also states that decolonizing the curriculum is necessary for decarbonizing due to the necessity for climate justice and addressing the systems leading to climate change [37].

Arguments for Just Transition and Climate Justice generally take a normative or positive approach. Normatively, it is argued that improving lives and redressing wrongs is a moral obligation; positively, it is argued that justice will maintain or enhance the social license of governments, corporations, etc., to operate [38]. Climate justice initiatives in higher education have been put forward to contain both climate justice frameworks and an energy democracy approach that focuses on challenging power imbalances, i.e., following the normative approach [12]. For curricula this means "cross-cutting curricula linking climate justice across disciplines, programs, departments, and schools", whilst the Mary Robinson Foundation has defined climate justice to mean "Climate justice links human rights and development to achieve a human-centered approach, safeguarding the rights of the most vulnerable people and sharing the burdens and benefits of climate change and its impacts equitably and fairly" [39].

In searching for a roadmap to a new pedagogy, it is necessary to determine what we are seeking to change. Drawing on the definitions, we discuss the methods, strategies, theories, principles, and practices of teaching (i.e., the "how" and the "why" of teaching). The fundamental "why" behind this research is sustainability. However, the "how" aspect remains an open question. Additionally, we consider the design, implementation, and evaluation of curricula (i.e., the "what" that is being taught, or the contents of curricula). This paper begins by reviewing the influences on curriculum and pedagogical change. The subsequent sections are dedicated to the methodology, results, and analysis of this study. Finally, this study concludes with relevant suggestions for furthering the decarbonization of curricula and pedagogy in higher education.

2.1. Influences on Higher Education Change

This study does not concern the physical decarbonization of educational buildings or Scope 1 and 2 emissions, which have been covered previously (e.g., The School Decarbonization Challenge by the Energy Systems Catapult [40], or the University of Exeter's Green Strategy Plans [7]). Instead, this work concerns pedagogies, curricula, and the teaching and research related activities of academics. Various means by which pedagogies and curricula are influenced to change will be discussed.

Research on learning and cognitive psychology has the potential to inform and shape teaching methods and pedagogies. Six specific cognitive strategies, thoroughly validated through decades of research, include spaced practice, interleaving, retrieval practice, elaboration, the use of concrete examples, and dual coding [41,42]. For instance, the University of Edinburgh employs a web-based tool called PeerWise to support spaced practice, elaboration, and dual coding among students. With PeerWise, students can create, share, and respond to multiple-choice questions related to course topics, fostering regular review, the establishment of connections, and the utilization of both words and images to enhance learning [43].

Similarly, the University of Wisconsin utilizes CogSketch, a web-based tool, to facilitate dual coding and the incorporation of concrete examples in student learning [44]. CogSketch is a sketch-based learning environment that enables students to draw diagrams and sketches to represent and elucidate concepts in science and engineering, encouraging the use of both verbal and visual information for encoding and retrieval, employing concrete examples to illustrate abstract principles [45]. Additionally, the University of California, San Diego, employs Interleaved Mathematics Practice, a web-based tool, to promote interleaving and spaced practice among students [46]. This homework system assigns problems from different topics in a mixed order rather than in blocks of the same topic, enhancing retention and transfer of knowledge [47].

As educators gain deeper insights into the intricate processes of learning and the underlying neurological mechanisms at play during educational experiences [48,49], they are better equipped to make targeted improvements in teaching practices. Recent research has underscored the importance of integrating neurobiological insights into educational practices, emphasizing that these insights can inform the development of effective teaching strategies that optimize information retention and learning [3]. For example, understanding the neural correlates of memory formation can lead to the development of instructional strategies that enhance memory retention [50]. By incorporating brain-based research findings into the classroom, educators can significantly improve teaching efficacy. The application of neurobiological insights can facilitate the creation of teaching methods that align with the brain's natural processes, enhancing students' ability to grasp and retain information. However, the dissemination of this knowledge to educators is crucial, as it can lead to an increased understanding of cognition and brain function and the adoption of active-learning pedagogies [49]. Therefore, the integration of neurobiological insights into educational practices has the potential to not only enhance teaching and learning outcomes but also contribute to the broader advancement of pedagogical practices. Recognizing the transformative impact of neurobiological research on education, it becomes imperative for educators to stay informed and actively apply these insights in their teaching methodologies. Furthermore, the scholarship of teaching and learning (SoTL) provides opportunities for clinical faculties and preceptors to engage in research and scholarship around teaching and learning, further contributing to the advancement of pedagogical practices [51].

Advancements in technology have the potential to revolutionize the teaching and learning process. This includes the provision of innovative resources and tools, along with a fundamental shift in the delivery of didactic resources, making a substantial contribution to the seamless integration of SDGs. Educational technology has already had a profound impact on teaching and learning in the Pre-K-12 environment, with content neutral technologies being used to customize students' learning experiences [52]. Emerging technologies such as augmented reality and virtual reality (AR/VR), mobile learning devices, and the internet of things (IoT) offer new opportunities for promoting sustainability within university teaching and learning [53].

The use of new technologies in education facilitates and strengthens the teaching and learning processes, offering virtual tools that promote knowledge sharing, critical thinking, and skill development [54]. Technology enables communication and collaboration among students, allowing for group discussions and collaborative projects using tools like Zoom, Google Meet, wikis, and cloud-based apps [55]. Notably, 82% of teachers in the United States believe that leveraging technology enhances students' readiness for future careers [56]. In Australia, 48% of teachers express a keen interest in enhancing their professional development through digital learning methods aimed at engaging students [57]. Furthermore, an impressive eight in ten teachers in New Zealand affirm that the integration of digital technologies is positively influencing student achievement [58].

Studies have demonstrated that AR/VR technologies hold significant promise as valuable contributions to the educational technology "edtech" domain [59]. This is attributed to their immersive qualities, capacity to present information in innovative and captivating formats, and the potential to provide virtual experiences that can overcome challenges related to cost or distance. While still in its nascent phase, there are numerous encouraging instances of this technology being actively employed in K-12 education, higher education, and teacher training. Its applications span various domains, encompassing STEM education and technical training, as well as the arts and humanities.

For instance, AR/VR technologies hold promise in creating immersive learning experiences that can enhance students' understanding of sustainability concepts [60]. Virtual simulations can provide a virtual environment for students to explore sustainable practices and witness the consequences of various choices on the environment. This immersive quality of AR/VR can bridge the gap between theoretical knowledge and real-world applications in sustainable development. However, the effective integration of technology into higher education also poses challenges, including the need for digital literacy and accessibility considerations [61]. Addressing these challenges is crucial to ensuring that technological advancements align with the principles of sustainability and inclusivity within the educational context.

The ongoing fourth industrial revolution, characterized by technological advancements like the IoT, artificial intelligence (AI) and Big Data [62], requires higher education institutions to revamp their curricula to prepare students for the evolving job market [63]. The continuing social, political, economic, and technological shifts are influencing individuals' lifestyles, work patterns, and educational pursuits. It appears that nations, irrespective of their current developmental stage, will experience a digital transformation due to the unprecedented speed at which technology is being adopted [64]. Within the university context, digital technologies significantly influence conventional educational frameworks, altering operational dynamics, instructional delivery methods, and student engagement approaches. This phenomenon acts as a catalyst for digital transformation, prompting universities to undergo evolution and adjustment in response to the evolving digital landscape.

Digital transformation extends beyond the mere adoption of new technologies; it encompasses substantial organizational changes to embrace digital practices and capabilities. While digital disruption concentrates on the particular effects of digital technologies on universities and education, digital transformation encompasses the more extensive organizational adjustments necessary to leverage the potential of digital technologies and establish a digitally oriented institution. Recent work in education research and policy studies has questioned the idea that education alone can fix social problems [65]. This skepticism is related to changes in job markets, whereby changes in the demand for certain skills required by employers can drive changes in education to prepare students for these job market changes [66]. In response to these challenges, numerous universities are transitioning towards a more business-oriented model [67] to meet the expectations of students seeking skills aligned with social needs [68].

Despite various initiatives in recent times aimed at education for sustainable development, there is a lack of effective implementation, especially within higher education, in a comprehensive manner. This problem includes addressing aspects such as curriculum, diverse disciplines, the three dimensions of sustainable development, teachers' attitudes, content related to sustainable development, and the pedagogical content knowledge necessary for education for sustainable development that can bring about institutional change [69]. The challenges identified include the need to establish consensus on diverse agendas, foster collaboration in teaching, address the lack of training in teaching education for sustainable development, rectify the limited inclusion of education for sustainable development content in some syllabi, and address the shortage of experts in education for sustainable development among teacher educators [70].

Education is a dynamic process that evolves alongside society's changing expectations. It can adapt to reflect shifts in values, such as promoting social equity and inclusion, as well as respond to changes in the economy. The COVID-19 pandemic has accelerated the need for changes in teaching methods, leading to a global revolution in higher education [71]. As educational facilities closed, digital technology gained the stage in national programs to improve and extend remote learning and create more inclusive and adaptable education systems [72]. The e-learning market is expected to reach USD 848.12 billion by 2030, with a Compound Annual Growth Rate (CAGR) of 17.54%, indicating an increasing embrace of online educational platforms and digital learning resources [73].

Finally, it is crucial to acknowledge the transformative role of student feedback in shaping education programs and practices. As educators endeavor to meet the dynamic needs of students, their input becomes a powerful catalyst for change [74]. However, navigating the delicate balance between integrating student feedback and adhering to academic standards and learning outcomes poses a significant challenge. The evolving landscape of higher education, influenced by factors such as technological advancements, societal shifts, and global events like the COVID-19 pandemic, underscores the importance of a nuanced approach to pedagogical adaptation [75].

The ability to assimilate feedback effectively requires educators to critically assess and reconcile the evolving demands of students with established academic standards [76]. Striking this balance ensures that educational programs remain responsive to student needs without compromising the integrity of learning objectives. Collaboration and the exchange of best practices among educators, both within and across institutions, emerge as valuable strategies in this endeavor. Such collaborative efforts not only facilitate the sharing of insights but also contribute to the continuous improvement of teaching methods and content.

2.2. Barriers and Opportunities for Higher Education Decarbonization

The decarbonization of higher education institutions faces several barriers, including carbon lock-in, financial costs, and administrative challenges. Carbon lock-in, which perpetuates the fossil fuel energy system, can hinder the adoption of low-carbon technologies in these institutions [77]. To approach this research methodically, criteria for categorizing barriers to, and opportunities for decarbonization were sought. Categories of barriers to and opportunities for decarbonization (across Europe) have been identified as shown in Figure 3, to which we have added Administrative and Student for this study [78].

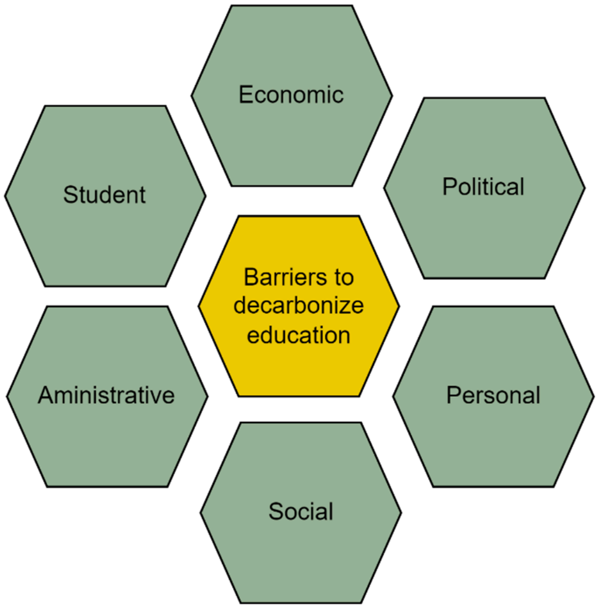

Figure 3. Main barriers to decarbonizing education systems (source: authors).

2.2.1. Economic

We perceive economic barriers and opportunities as encompassing factors associated with research funding, university activities financing, and their impacts on the higher education sector.

A prominent and oft used criticism in this area is the prominence of fossil fuel funding for research and universities [79], which, particularly in the US, is very large (e.g., the influence of the Koch family is well documented) [80]. The provision of or the removal of this funding has a large sway over the financial viability of institutions and individuals' research, and therefore the influence of the funding source cannot be ignored.

Related to the issue of funding is the divestment movement, now pursued by over 100 UK universities, primarily as a moral imperative, though with increasing concern over the long term financial viability of fossil fuel intensive industries [81]. The divestment movement seeks to limit capital flow to fossil fuel intensive companies, and in doing so seeks to limit their growth or destroy their capital [82]. The scale of the influence of the higher education sector in this practice is unclear, though the Dallas Fed Energy Survey for Q2 of 2022 notes "Private investors like endowments and foundations are structurally gone for good, and it is actually different this time" [83].

In the UK, the means of university funding is devolved and in England is currently primarily through tuition fees, which have been abolished in Scotland [84]. This has not always been the case, as in 2010 the majority of funding came from Funding Councils, with this funding being an object of much political debate over the decade of the 2010s [84]. Broadly speaking, research funding has remained stable whilst teaching funding has been cut. As such, there exists a disincentive for higher education institutions to oppose prevailing political sentiments and norms, and an incentive to seek alternative funding such as that from fossil fuel industries.

A consequence of lack of funding, particularly in teaching, is twofold: (i) a lack of teaching resources and staff, and (ii) limited access to technology. This limits opportunities to reform and modernize what and how students are being taught. Furthermore, it is noted that most research funding is spent on STEM rather than social sciences, leading to a limited number of perspectives and methodologies being applied [85].

2.2.2. Political

We consider political barriers and opportunities to be those associated with domestic and international political relations, intra and interstate. We categorize "political" barriers within the higher education sector in either the Personal or Social sections as appropriate.

The primary political barrier identified pertains to diversity and power structures. Many universities are considered to lack diversity, particularly in the fields of science and engineering, which places a limit on the perspectives applied to, and connections made between science and the wider world [86]. This is also related to the economic barriers concerning funding, universities' relationships with contemporary governments, and their attitudes toward power structures. For example, in Canada, there are ongoing financial restraints and a renewed interest in university research, which have implications for academic decision-making bodies [87]. The power structures within universities are complex and varied, involving faculties, students, administrators, governing boards, and presidents. Conflict and friction can arise among these groups, affecting educational policy and practice [88]. State governments and public colleges in the US have a symbiotic relationship, but state support for higher education has been declining due to economic recessions and a conservative shift in the federal government's role. This has led to a fundamental change in the relationship between states and public higher education, with universities increasingly relying on tuition and private support [89].

A further consideration is that the shape of curricula is inherently political [90]. The lack of a rigorous Marxist theory of the state and the international has led to discussions about what a Marxist theory of imperialism and international relations would look like [91]. A Marxist theory of the international can incorporate political concepts from mainstream theories of IR, taking into account the uneven development of capitalism at different levels [92]. Where such curriculum contents clash with the SDGs beyond decarbonization, such as SDG 17 regarding cooperation, might pose a barrier to decarbonization.

Other political obstacles include the influences of domestic political leadership [93], policy inconsistency and short termism [94], partisan politics, and lobbying [95]. That is to say that a chicken and egg problem arises concerning leadership and its legitimacy on climate action; leaders are reluctant to lead without comprehensive direction from electorates, who expect politicians to take action in these areas [93]. Policy inconsistency leads to repeated curriculum change (and changing budgets) [94]. Partisan politics and lobbying lead to the "watering down" of decarbonization efforts [95].

2.2.3. Personal

Personal barriers and opportunities are those related to the personal psychology, motivations, and personal working habits of individuals within the higher education system, either students or teaching and research staff.

We consider Jost's theory of system justification to be a personal barrier [96]. Jost's "A Theory of System Justification" posits that consciously or unconsciously, defending the status quo serves fundamental psychological needs for certainty, security, and social acceptance. This motivation to maintain the current social structure is driven by a desire to feel positive about ourselves, and our place in society, even at the expense of others. Jost's theory is relevant to decarbonization in that we can infer that individuals within higher education are therefore psychologically predisposed to maintaining current curricula and pedagogies that directly or indirectly serve the interests of fossil fuel companies. Overcoming this barrier requires individuals to go against a system, or a large mass of individuals to demand system change simultaneously.

Academic careers are widely known to be scarce and highly precarious. For example, a report released by The Royal Society in 2010 stated that only 3.5% of those who complete a PhD manage to secure a permanent research position at a university, with just 0.12% of those PhD graduates ever becoming full professors [97]. Given this insecurity, there is a disincentive to participate in movements that upset the status quo in the sector. Related to this point is the large workload placed on academic staff [91]. These time constraints and workload pressures are known to hinder creativity and the ability to participate in processes that may change higher education [93]. In turn, a cascading consequence of this effect is the lack of awareness among educators of the potential for change.

The capabilities of academic staff can also pose a limitation to decarbonizing curricula, depending on their ability to convey information and their personal beliefs regarding decarbonization. We have, however, not collected data on this aspect due to ethical issues; for example, we do not wish to ask respondents to undermine the standards that their university sets for teaching by asking their personal views on the competence of their colleagues.

Lastly, students do not pursue higher education solely for their passion for a given subject, but also due to the desire to pursue a particular career path [98]. When this desire for stability in future career paths is predicated upon interaction with fossil fuels, there is a further disincentive for change.

2.2.4. Social

Social, cultural, and behavioral dynamics play a pivotal role in the decarbonization of higher education, shaping both challenges and opportunities. The intricate interactions between individuals, coupled with the general influences of institutional culture and politics, contribute to a dynamic social context that influences decarbonization efforts.

Eminent scholars such as Higham and Font, as well as Poggioli and Hoffman, contend that academia, marked by frequent air travel in a pervasive "flyout" culture, operates as a carbon-intensive industry, increasingly viewed as a manifestation of "climate hypocrisy" [95,96]. While technological advancements offer limited mitigation for the environmental impacts of air travel, the imperative for behavioral change is undeniable [99]. Moreover, these scholars assert that academics often engage in moral disengagement, rationalizing their actions and overlooking the ecological consequences of their travels. Addressing this issue necessitates a dual commitment: academic institutions assuming responsibility and individual academics setting an example by conducting impact audits and exploring low-carbon business models [100].

Cultural and institutional constraints manifest in the resistance to decarbonization of pedagogy and curricula, presenting unique challenges. The implementation of innovations to curricula is influenced by local culture and classroom dynamics during the decolonizing process [101]. The increasing recognition of the need to decolonize curricula and pedagogy in higher education primarily focuses on addressing the perpetuation of specific epistemological perspectives and the attainment gap [102]. However, initiating curriculum changes may face opposition from students or the broader community, a recurring issue across subjects ranging from climate change to race [98,103]. This resistance underscores the importance of understanding behavioral aspects in driving change. For instance, garnering support for any transformative change becomes a protracted and intricate process, entwined with cultural and behavioral barriers, where the deficiency of political leadership on climate action surfaces as a critical challenge [93].

Overcoming these social, cultural, and behavioral impediments requires a nuanced understanding of institutional dynamics, coupled with proactive measures to foster a culture of sustainability and inclusion within higher education.

2.2.5. Administrative

We conceptualize administrative barriers and opportunities as factors entrenched in intrainstitutional regulations, organizational processes, management practices, decision-making protocols, and overarching national regulations governing higher education.

The accreditation of many courses by national bodies, such as the Institution of Mechanical Engineers, serves as a critical indicator, both nationally and internationally, attesting to the quality of the respective courses [104]. Subsequently, institutional policies and regulations concerning pedagogical modifications become significant, necessitating the delineation of learning outcomes and imposing a level of curricular standardization. This standardization, while promoting consistency, inadvertently acts as a deterrent to change, hindering the seamless integration of novel elements, some of which could be pertinent to decarbonization efforts. Compounding this challenge is the existence of a "first mover" penalty for institutions proactive in changing their curricula before broader standards evolve.

Furthermore, particularly within the physical sciences, certain curricula content's energy intensiveness presents a formidable barrier, as mainstream low-carbon alternatives are currently nonexistent for incorporation into courses.

Expanding our focus on pedagogy at large, the prevalent reliance on standardized testing and outdated evaluation and feedback mechanisms pose constraints on the adoption of innovative pedagogical approaches and curricular changes [66]. Overcoming these administrative challenges requires a nuanced understanding and strategic navigation of both intrainstitutional and national regulatory landscapes.

2.2.6. Student

In this study, we define student barriers as challenges related to both the ability and willingness of students to adapt to novel teaching content and methods. The contemporary job market poses formidable obstacles for graduates, encompassing factors such as insufficient relevant work experience, limited access to job search information, and elevated work-seeking costs, all of which impede successful employment [105]. This predicament is further intensified by fierce competition among employers vying for top-tier graduates [106] and a perceptible misalignment between employer expectations and the competencies possessed by graduates.

The prevailing incentive for students to attain the highest possible grades amplifies this scenario, as grades function as the primary discriminant in the competitive graduate job market [107]. Consequently, this engenders a motivation for students to employ any available means to secure a high grade, potentially leading to strategic avoidance of challenging courses, thereby compromising a comprehensive understanding of academic materials.

Additional challenges manifest in various forms, including a lack of preparedness for rigorous courses [108], acclimatization to specific assessment types, resistance to change, the emergence of eco-anxiety resulting in a state of paralysis rather than proactive engagement [109], and the pervasive influence of misinformation on students' perceptions and comprehension of SDG related content [110]. Furthermore, students may face challenges in adapting to new learning environments, such as the shift to online learning during the COVID-19 pandemic [111].

3. Method

In this section, we provide a comprehensive overview of the methodological framework employed in our study, encompassing the research design, participant recruitment strategies, survey development process, detailed data analysis procedures, and a critical exploration of the study's limitations.

3.1. Research Design Overview

To comprehensively address the integration of the UN SDGs into teaching and research, our study employs a multifaceted approach that involves both esteemed academics and recognized experts across diverse sectors, including public, private, and nonprofit organizations, as shown in Figure 4.

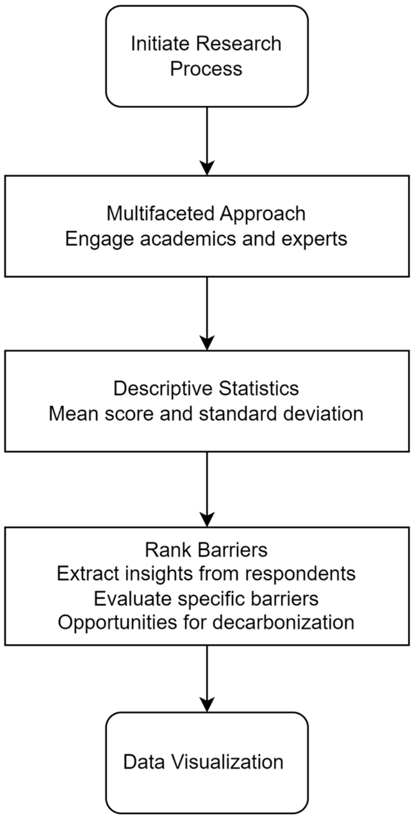

Figure 4. Main steps of the methodology flow process.

The survey aims to extract valuable perspectives on overcoming barriers related to SDGs and discern potential threats impeding progress. By engaging experts outside the confines of academia, we seek practical insights derived from real-world applications. This external perspective will enable us to guide academic efforts more effectively, aligning teaching and research with tangible actions taken in various sectors.

Simultaneously, a targeted exploration within academia will delve into the specific challenges hindering the seamless integration of SDGs into teaching and research practices. This internal inquiry provides a platform for researchers to candidly discuss these challenges in a systematic and in-depth manner, surpassing the constraints of conventional discourse.

Through this dual-pronged methodology, we aspire to bridge the gap between theoretical understanding and practical implementation, fostering a more robust and informed approach towards achieving the UN SDGs in academic and real-world contexts.

3.2. Participant Recruitment

Participants for this study were recruited through a targeted and diversified approach. The recruitment process aimed to ensure representation from both academia and various other sectors, including public, private, and nonprofit organizations.

1. Potential participants were identified based on their roles in academia or relevant sectors associated with the study's focus on overcoming barriers to decarbonizing higher education.
2. Invitations to participate were extended via email, and potential participants were provided with a clear overview of the study's objectives, emphasizing the importance of their insights.
3. Participants were informed about the voluntary nature of their involvement, the anonymity of their responses, and the intended use of the collected data. They were required to provide explicit consent before proceeding with the survey.

4. To ensure a comprehensive understanding, efforts were made to recruit participants with diverse demographic characteristics, including geographical location, gender, employment rank, and field of expertise.

This recruitment strategy aimed to gather a well-rounded perspective on the challenges and opportunities related to decarbonizing higher education, thereby promoting a more inclusive and insightful analysis.

3.3. Survey Development

In our pursuit of a comprehensive understanding of the challenges and possibilities associated with decarbonization, our survey instrument is meticulously designed to extract insights from respondents. The survey probes into the nuanced landscape of barriers and opportunities surrounding decarbonization. Beyond mere identification, our instrument endeavors to elucidate the relative significance attributed by respondents to various barriers and solutions within the context of decarbonizing third-level education. This strategic approach aims to unveil a prioritized roadmap for the removal or incorporation of these elements.

The survey itself, outlined in the subsequent sections, employs targeted questions tailored to meet the specific research objectives of our project, supplementing the core data with additional insights wherever possible.

The overarching objectives of this household survey can be distilled into four focal points:

1. To Establish a Hierarchical Framework of Barrier Categories: Our primary aim is to discern distinct categories of barriers and establish a hierarchy, providing a nuanced understanding of their interplay and relative significance in the decarbonization landscape.
2. To Unveil a Hierarchy of Specific Barriers within Categories: Delving deeper, we seek to unravel the intricacies within each identified category, discerning a hierarchy that sheds light on the specific challenges that demand targeted attention.
3. To Propose Solutions to Overcome Barriers: In tandem with identifying barriers, our survey endeavors to elicit from respondents a set of viable solutions, laying the groundwork for informed strategies to overcome the identified challenges.
4. To Assess Curriculum and Pedagogical Adjustments: Beyond barriers and solutions, we aspire to gauge the perspectives of respondents on the augmentation or elimination of elements within their curricula and pedagogies, contributing to the refinement of educational approaches in the context of decarbonization.

Carefully addressing these objectives, our research aims to be a pioneering contribution to the discourse on decarbonization in the realm of third-level education, offering not only a comprehensive analysis but also actionable insights for informed decision-making and strategic planning.

3.4. Data Analysis

In pursuit of originality rather than conventional novelty in concepts or methodology within the realm of social sciences [112], our survey was systematically crafted with a distinctive focus. Unlike studies that mainly rely on theoretical frameworks, our approach was based on a deliberate decision to create a survey aligned with the overarching goals of the project while avoiding predefined hypotheses adjusted to match collected data.

Our survey instrument, presented in Table 1, demonstrates our commitment to a comprehensive approach. It was carefully developed based on a thorough literature review, prioritizing simplicity, clarity, and participant engagement. The questionnaire, consisting of 16 questions, was structured to be completed within approximately 15 min, recognizing the value of participants' time. Moreover, to enhance engagement, a concise brief was strategically employed to inform respondents about the study's scope.

Table 1. Overview of survey questions and response options.

Question	Answer Options
Which country do you work in?	List of countries
Which category best describes your place of work	University, Public Sector, Private Sector, Third Sector, Other
What is your gender?	Male, Female, Prefer to self-describe, Prefer not to say
What rank best describes your current employment?	Postgraduate Researcher, Junior Academic, Senior Academic, Junior Employee, Middle Management, Senior Management
What is your field of expertise/training?	Physical sciences, Biological sciences, etc.
Please rank the following barriers to decarbonizing higher education (pedagogy and curricula)	Economic, Political, Personal, Social, Administrative, Add other box with free entry. 1 is highest, 5 is lowest
How large a barrier to decarbonizing higher education (pedagogy and curricula) do you consider the following economic barriers	(A) the role of fossil fuel funding in research and teaching. (B) Lack of teaching resources and staff. (C) Limited access to technology. (D) Allocation of research and teaching funding across subjects
How large a barrier to decarbonizing higher education (pedagogy and curricula) do you consider the following political barriers	(A) Lack of diversity (race, gender, nationality, etc.) in higher education teaching and research. (B) Inadequacy and uncertainty of government funding. (C) Existing power structures and power dynamics in society. (D) Government influence on research and teaching topics
How large a barrier to decarbonizing higher education (pedagogy and curricula) do you consider the following personal barriers	(A) Defending status quo as a psychological need for safety, certainty and social acceptance. (B) The precarious nature of academic careers. (C) The scarcity of academic positions. (D) Students' desire to pursue a certain career path
How large a barrier to decarbonizing higher education (pedagogy and curricula) do you consider the following social barriers	(A) Commonly accepted high carbon behaviors in academia e.g., frequent flying for conferences. (B) Cultural constraints on curricula and pedagogy, e.g., backlash to curriculum change. (C) Institutional constraints on curricula and pedagogy, e.g., developing "buy in" among staff. (D) Lack of awareness of issues pertaining to decarbonization among research and teaching staff
How large a barrier to decarbonizing higher education (pedagogy and curricula) do you consider the following administrative barriers	(A) The need for course accreditation. (B) Institutional regulations regarding pedagogical and curriculum change. (C) "first mover" penalty for those institutions who do change their curricula before standards change. (D) the energy intensiveness of some curricula content e.g., certain manufacturing processes, is such that no mainstream low carbon alternative exists to be incorporated into the course
How large a barrier to decarbonizing higher education (pedagogy and curricula) do you consider the following barriers relating to (undergraduate and postgraduate) students	(A) Due to job market pressures, students prioritize achieving as high a grade as possible even if this is to the detriment of spending time understanding academic content. (B) Students insufficiently prepared by prior education for the course they are undertaking. (C) Student familiarity with a certain type of assessment or course content leads to resistance to change. (D) Inconvenience: Students may view a change in pedagogy as inconvenient, requiring more effort or time on their part.
How important do you consider the following as opportunities for decarbonizing higher education (pedagogy and curricula)	(A) The divestment movement as a catalyst for further change. (B) Advances in research in learning and cognitive psychology. (C) Evolution of societal norms. (D) Student feedback. (E) Collaboration and sharing of best practice among educators. (F) Diversifying climate change related subjects that funding is allocated to for teaching and research. (G) Reduced precarity of academic employment
What one thing would you add, and what one thing would you remove, from your curriculum to further decarbonize higher education	
What one thing would you add, and what one thing would you remove, from how you teach (your pedagogy) to further decarbonize higher education	
Have you any further comments to add to this work?	

The survey used a structured assessment to investigate barriers to decarbonizing higher education, emphasizing pedagogy and curricula. Participants were asked to rate economic, political, personal, social, and administrative barriers to comprehensively understand the challenges. Furthermore, respondents were asked to evaluate the specific size of barriers within each category, which allowed for a more detailed understanding of their perceived relevance.

Beyond identifying challenges, our survey investigated prospects for decarbonizing higher education by questioning participants on various catalysts. These drivers included the divestment movement, learning psychological improvements, cultural norms evolution, student feedback, educator collaboration, and the diversity of climate change-related disciplines. In addition, we examined reducing academic job uncertainty as a potential catalyst.

To capture qualitative insights, open-ended questions were strategically integrated into the survey. Participants were encouraged to suggest additions and removals from curricula and pedagogy, fostering a comprehensive understanding of their perspectives. This approach emphasized the deliberate survey design choices, ensuring transparency in the methodology employed for data collection.

The questionnaire was divided into three sections: the first dealt with respondent demographics, while the second and third looked at challenges and solutions to higher education decarbonization. Furthermore, recommendations for improving or streamlining higher education pedagogy and curricula relevant to domestic and transportation energy use were gathered. The survey was done online using Qualtrics, the leading online survey implementation platform, and included a variety of response styles such as Likert scales, categorical ranks, and open-ended questions.

It is noteworthy that, to ensure the integrity of participant responses, our survey maintained a deliberate absence of direct contact or incentives. All respondents were adults aged 18 years or older. The final dataset comprised insights from 48 respondents, and a detailed demographic breakdown is available in Table 2. Descriptive analysis was employed to interpret and explain the survey findings, providing a comprehensive understanding of the diverse demographics of the survey respondents and ensuring transparency and clarity in the participant profile.

Table 2. Demographic profile of survey respondents.

Total Samples	
Gave consent to participate	48
Country	
United Kingdom of Great Britain and Northern Ireland	9
Ireland	4
Canada	2
Switzerland	2
United States of America	2
Australia	1
Austria	1
Belgium	1
China	1
Finland	1
India	1
Italy	1
Netherlands	1
New Zealand	1

Table 2. *Cont.*

Total Samples	
Nigeria	1
Pakistan	1
Zambia	1
Total	31
Gender	
Male	28
Female	12
Prefer to self describe	0
Prefer not to say	0
Total	40
Place of work	
University	31
Public Sector	3
Private Sector	5
Third Sector	1
Other	0
Total	40
Employment rank	
Postgraduate Researcher	8
Junior Academic	7
Senior Academic	13
Junior Employee	0
Middle Management	4
Senior Management	6
Other	2
Total	40
Field of expertise/training	
Social Sciences	16
Natural Sciences	5
Formal Sciences	8
Humanities	1
Arts	0
Professions	5
Other	5
Total	40

The results regarding what should be added and what should be removed from curricula and pedagogy are outlined in Tables 3 and 4. Note that quotations have not been edited for spelling or syntax.

Table 3. Curriculum decarbonization recommendations: response to the question of what one thing would you add, and what one thing would you remove, from your curriculum to further the decarbonization of higher education?

Add	Remove
"Energy Economics"	
"Decentralised energy"	"Linear electricity (and gas) distribution grids."
"the lens of sustainability and global citizenship (not a subject but a lens into any and every aspect of university curricula)"	"Any subject that doesn't infuse or integrate sustainability into it"
"elegant integration of energy efficiency, renewable energy and energy storage"	"On-site use of diesel generators, wasteful building structures and transportation and commercial practices"
"social movements"	
"methods for co-production/stakeholder involvement"	
"Real life decarbonisation scenarios"	"Foundational courses in science e.g., Biology, Chemistry"
"Interdisciplinary courses"	
"a module in climate science"	
"in-depth ESG reporting (business school curriculum)"	
"more remote access"	"n/a"
"Funding"	

Table 4. Curriculum decarbonization recommendations: response to the question of what one thing would you add, and what one thing would you remove, from how you teach (your pedagogy) to further the decarbonization of higher education?

Add	Remove
"Field experiences"	
"More local case studies, problem based learning"	"Full length lectures"
"Imbibing psychological 'pushing' attitude towards decarbonisation into students; but that also needs this attitudinal change into other individuals"	"Attitude of seeing decarbonisation as merely an opportunity of saving money and being short-sighted"
"Greater saturation of smaller touching points infused and integrated into every subject/topic in every course"	"The approach that sustainability should be a topic and subject"
"Upgrading"	"Grading"
"outdoor pedagogy"	"international excursions/study trips"
"Virtual field trips"	"Physical field trips"
"Employing staff with industry experience"	"Less theoretical teaching"
"Problem-based learning"	"Lectures"
"mainstream sustainability through the entire curriculum"	
"More online session"	

With regards to items to add to curricula, a recurring theme is that of diversifying what is taught rather than deepening an existing knowledge area. For example, the addition of "the lens of sustainability" and "social movements" or "interdisciplinary courses". Meanwhile, items to be removed are those which are not future proofed, such as "linear... grids".

In terms of pedagogy, recurring items to add include "problem-based learning" and "field trips", whilst recurring items to be removed are also "field trips" and even "lectures". This set of conflicting results suggests that pedagogy itself is much more difficult to decarbonize than curricula and no clear direction emerges.

The hierarchy of barriers in the study was determined through a systematic analysis using descriptive statistics, specifically by calculating the mean score and standard deviation for each factor within the dataset. The mean score served as a central measure, offering an average perception of participants towards each identified factor. This provided a foundational understanding of the core challenges highlighted in the survey, acting as a synthesis of the problems.

Simultaneously, standard deviation was employed to assess the dispersion of scores around the mean. This statistical parameter played a crucial role in indicating the variability in responses, offering insights into the consensus or divergence among participants regarding specific challenges. The extent of agreement or disagreement among respondents was thereby revealed, adding details to the research findings.

By employing both the mean score and standard deviation, the study not only identified the average perception within each category but also the degree of variability or consensus, contributing to the establishment of a hierarchy of barriers. Factors with higher mean scores and lower standard deviations may be considered as more uniformly perceived challenges, potentially occupying higher positions in the hierarchy. Conversely, factors with lower mean scores and higher standard deviations may indicate greater variability in perceptions, influencing their placement in the hierarchy of barriers. This dual-pronged approach allowed for a comprehensive and nuanced determination of the hierarchy of barriers based on the participants' responses.

3.5. Limitations

This study acknowledges certain limitations inherent in its methodology that merit careful consideration. Firstly, the reliance on self-reported data introduces the potential for inaccuracies, as respondents may inadvertently provide information that is not entirely precise. Additionally, the exclusive use of self-reported data raises concerns about the ethical implications of obtaining information related to specific universities. Participants may be hesitant to disclose details about their colleagues or the activities of universities that have not explicitly consented to such inquiries.

To address the challenge of comprehensive data collection, we refrained from including questions that might have unveiled sensitive information. Instead, we encouraged respondents to supplement their responses with comments, striving to capture a broader perspective. It is important to note that our approach, while prudent, resulted in a limitation as it required us to minimize the number of questions posed to avoid overwhelming respondents.

Furthermore, three common limitations associated with surveys warrant consideration: acquiescence bias in responses, the potential impact of perceived social desirability [113], and variations in respondent knowledge. These factors underscore the need for cautious interpretation of our results and suggest avenues for further investigation.

For instance, when respondents express a desire for increased research funding for SDG related activities, it is crucial to recognize the potential influence of personal motivations. Researchers advocating for more funding may be driven by their professional aspirations, introducing a nuanced layer to their responses.

In light of these limitations, it is imperative to approach the findings with a degree of suspicion and recognize the potential for bias. The identified constraints also serve as guideposts for future research, directing attention to areas that require meticulous exploration and methodological refinement.

While the analysis provided valuable insights, it is important to acknowledge potential limitations, such as the reliance on mean scores and standard deviation. Future research may explore more advanced statistical methods to further delve into the relationships and nuances within the data.

4. Results

The outcomes of this investigation will delineate a set of priorities aimed at advancing the integration of net-zero principles into teaching and research, particularly within the framework of SDGs and Environmental, Social, and Governance (ESG) criteria. This, in turn, provides valuable insights into enhancing the educational experience for students who are destined to become the future workforce, business and political leaders, and responsible citizens.

The identified priorities serve as a roadmap for refining educational practices and aligning them with the imperative of sustainability. Furthermore, they lay the foundation for more effective preparation of students for their multifaceted roles in society. To maximize the impact of these findings, it is imperative to conduct a broader and more in-depth exploration of the uncovered priorities in the subsequent phase of this research. This will ensure a comprehensive understanding and facilitate the development of targeted strategies for effective implementation.

4.1. Barriers

The results regarding barriers to decarbonizing higher education are presented in Figures 5–11. Among the various categories, economic barriers emerge as the most prominent, overshadowing administrative, personal, social, political, and student-related factors. This observation aligns with the existing literature, which emphasizes the critical importance of overcoming barriers such as time constraints, financial costs, and data reliability in the assessment of greenhouse gas emissions [114]. Notably, administrative, personal, and social barriers emerge as equally important contributors to the challenges in decarbonization efforts. In the academic sector, administrative barriers escalate the private costs researchers encounter when attempting to decarbonize their research activities [115]. These results underscore the significance of directing attention and resources toward addressing challenges in research and teaching funding. Within the array of barriers, institutional administrative inertia emerges as a significant challenge. This inertia reflects a resistance to change within administrative structures, emphasizing the need to proactively address and dismantle bureaucratic impediments. By doing so, educational institutions can foster an environment that is conducive to embracing and implementing sustainable policies.

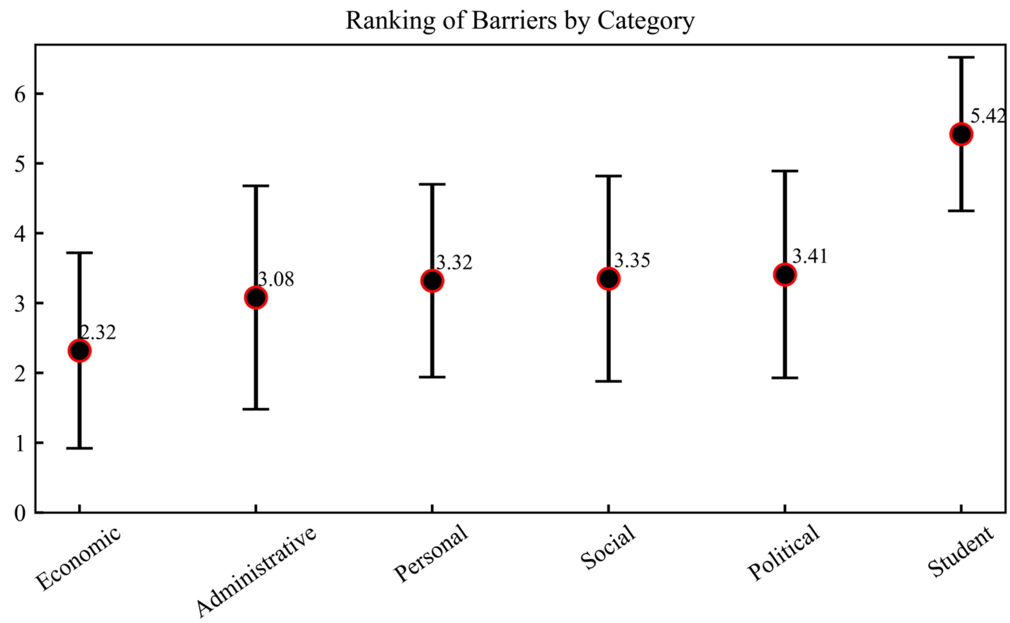

Figure 5. Mean ranking and standard deviation of barriers to decarbonizing higher education by category. The highest is 1, while 6 is the lowest.

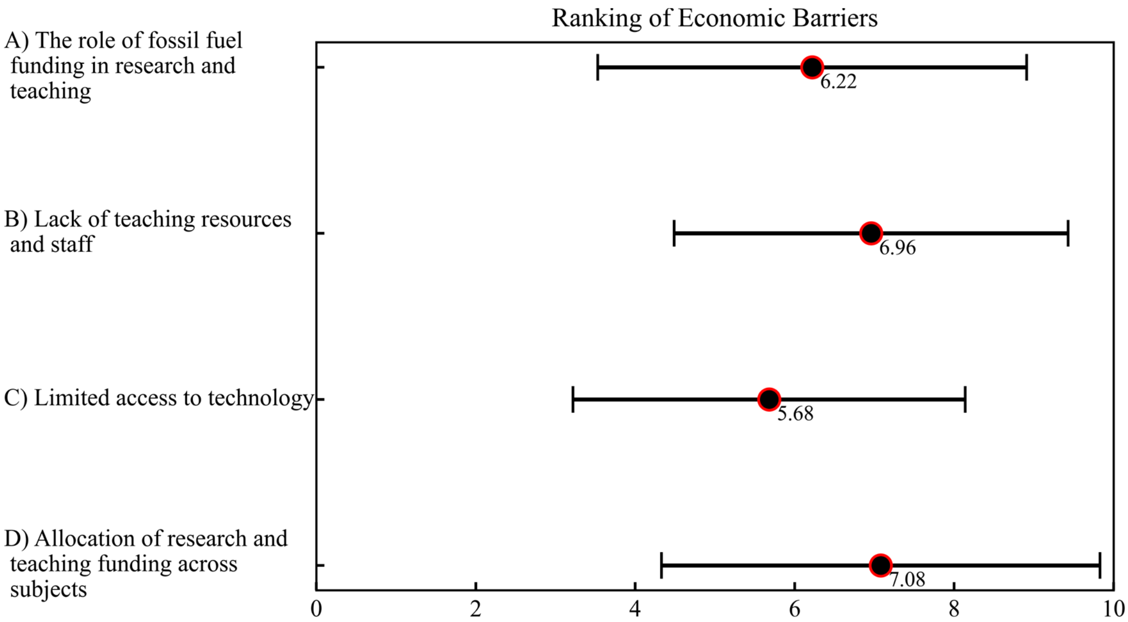

Figure 6. Mean ranking and standard deviation of economic barriers to decarbonizing higher education. The highest is 10, while 1 is the lowest.

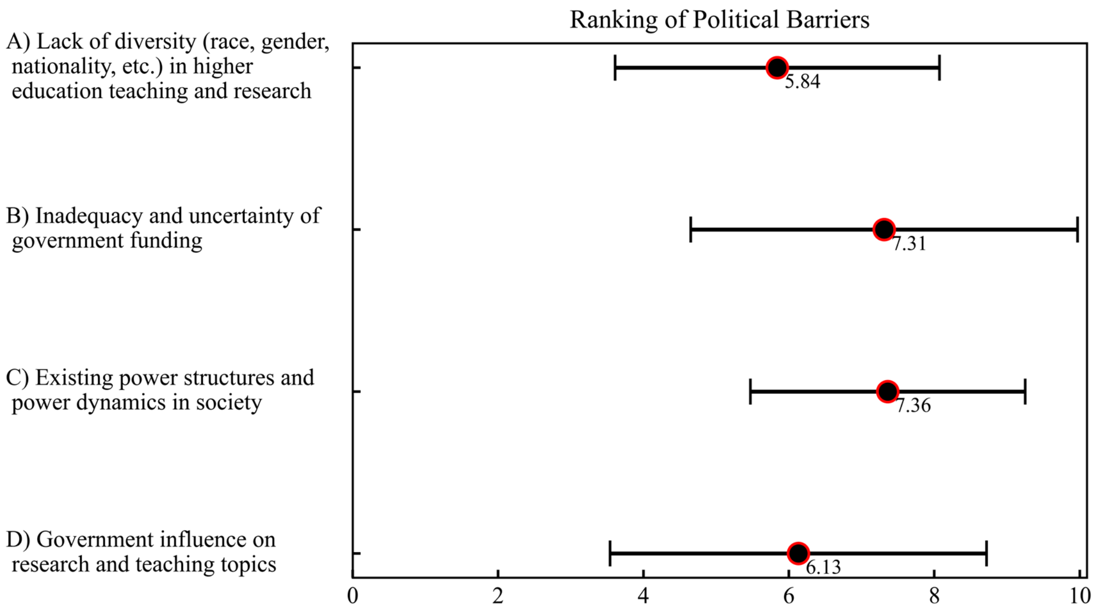

Figure 7. Mean ranking and standard deviation of political barriers to decarbonizing higher education. The highest is 10, while 1 is the lowest.

In light of these findings, it is recommended to prioritize the allocation of resources toward research and teaching funding as a foundational step. This strategic emphasis aims to address economic barriers and administrative inertia, setting the stage for a more seamless integration of sustainability measures. Investing in research and teaching funding not only supports the development of innovative green technologies but also facilitates curriculum enhancements that promote environmental awareness.

While acknowledging the importance of economic and administrative priorities, it is equally imperative to recognize that other categories, such as personal, social, and political factors, also play pivotal roles in the overall decarbonization process. Decarbonization requires changes in the social, technical, economic, and political systems that underpin modern societies [116]. Notably, student-related factors appear to have a comparatively lesser impact among the identified barriers. This may stem from factors such as limited awareness and engagement, less direct influence in administrative decision-making, challenges in changing entrenched behaviors, and resource constraints faced by students in contributing to decarbonization efforts within higher education institutions. These considerations highlight the need for a nuanced understanding of the distinct challenges associated with student-related factors in the broader context of sustainability initiatives. However, by strategically focusing on economic barriers and administrative inertia initially, institutions can establish a robust foundation for a comprehensive and sustainable approach to decarbonizing higher education.

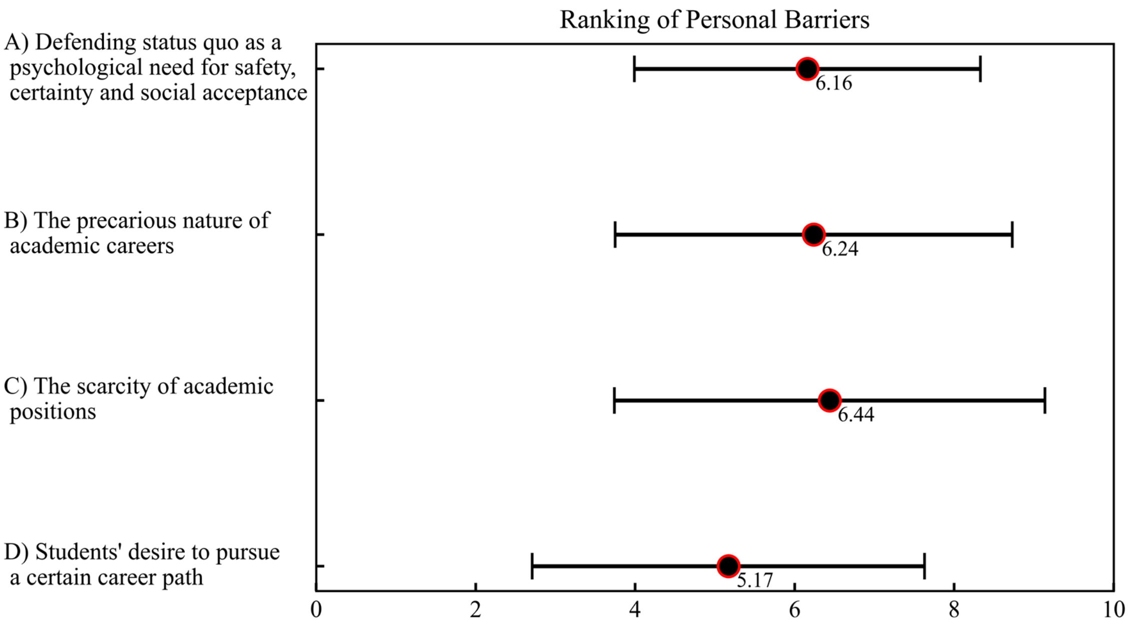

Figure 8. Mean ranking and standard deviation of personal barriers to decarbonizing higher education. The highest is 10, while 1 is the lowest.

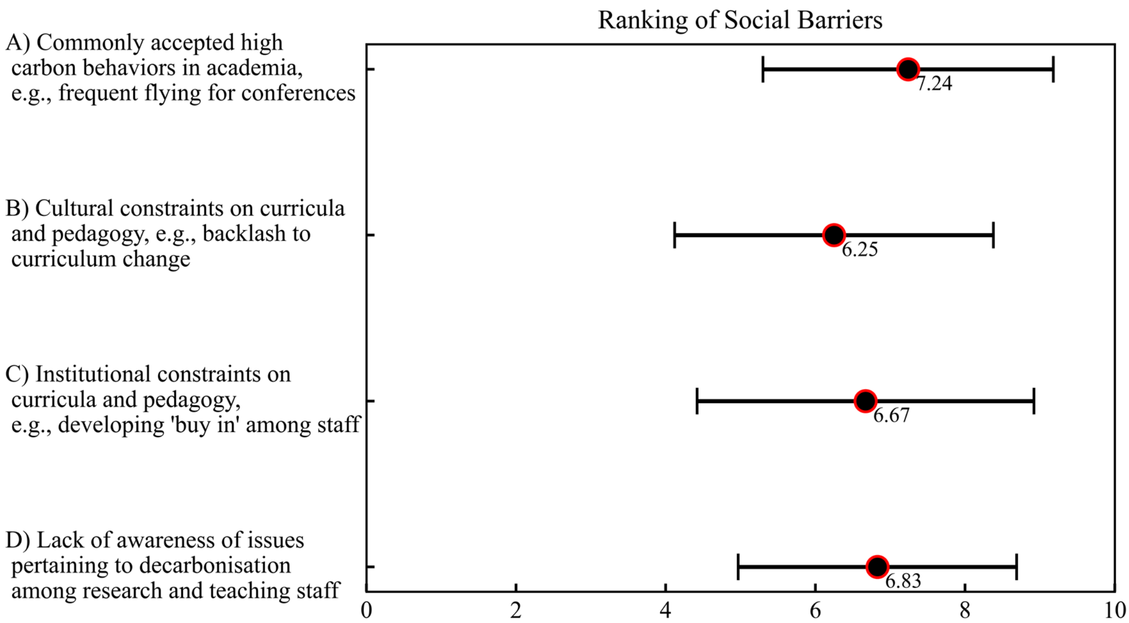

Figure 9. Mean ranking and standard deviation of social barriers to decarbonizing higher education. The highest is 10, while 1 is the lowest.

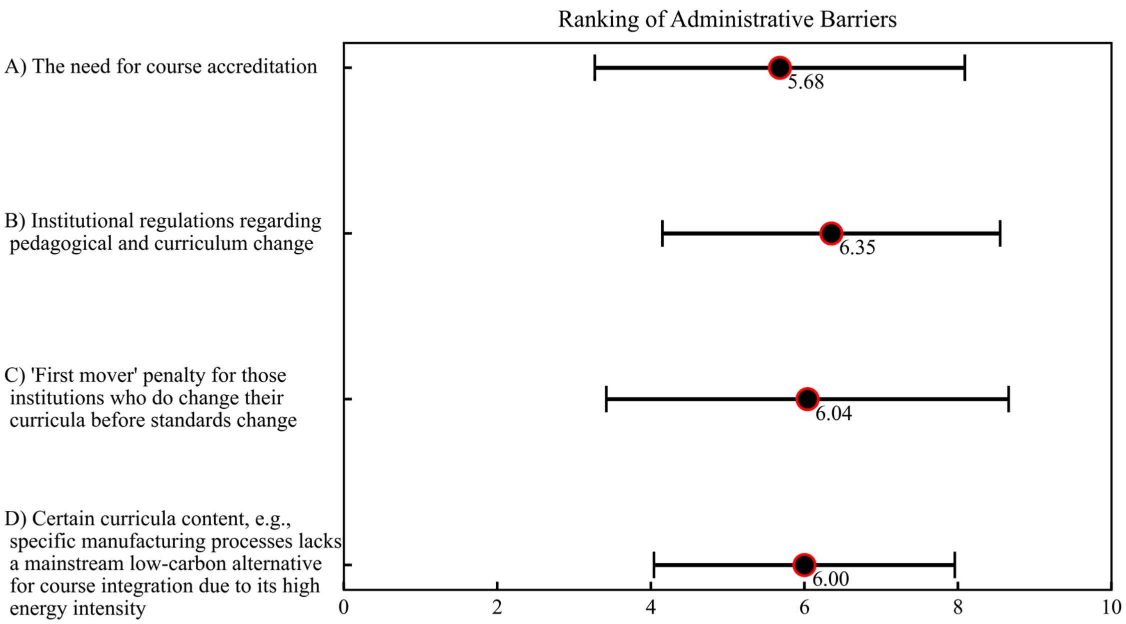

Figure 10. Mean ranking and standard deviation of administrative barriers to decarbonizing higher education. The highest is 10, while 1 is the lowest.

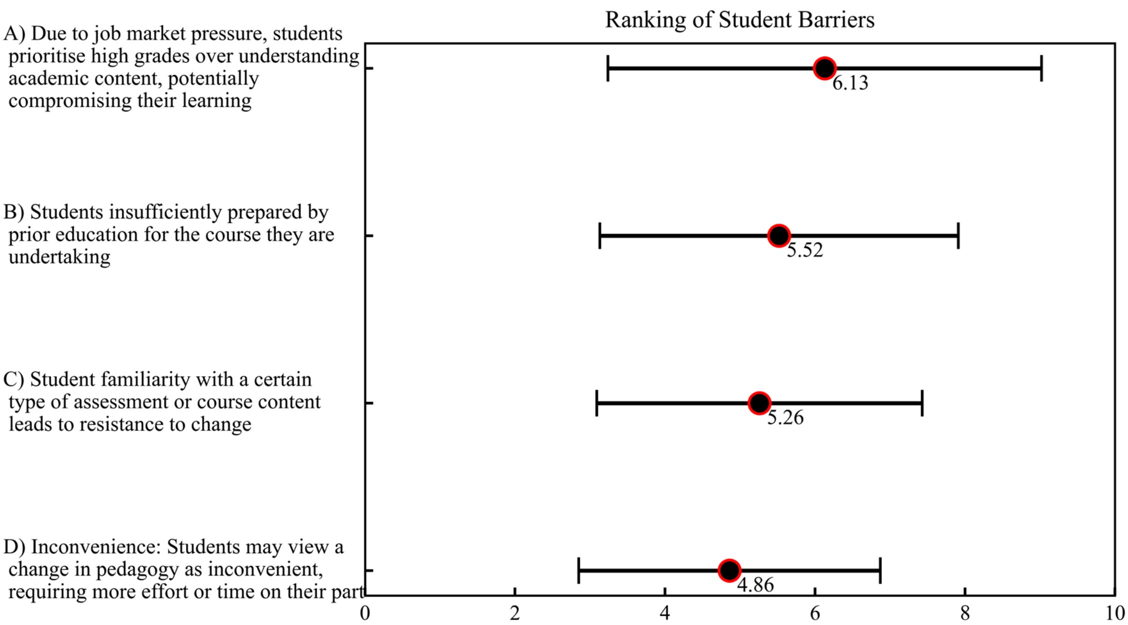

Figure 11. Mean ranking and standard deviation of student barriers to decarbonizing higher education. The highest is 10, while 1 is the lowest.

Figure 6 illustrates the survey results on economic barriers, revealing the following hierarchy from most effective to lowest: allocation of research and teaching funding across subjects, lack of teaching resources and staff, and the role of fossil fuel funding in research and teaching. The prominence of the allocation of research and teaching funding across subjects as the most critical economic barrier is justified by its overarching influence on the entire academic ecosystem. Our research aligns with previous studies [117] highlighting that challenges in enhancing school facilities, including integrating decarbonization efforts, stem from both insufficient funding and a dearth of expertise. Furthermore, our study acknowledges the pivotal role of higher education institutions in managing the carbon footprint, fostering public awareness, and educating future leaders. It is evident that the allocation of funding across subjects can influence the prioritization of decarbonization initiatives within these institutions [114].

Unequal funding distribution directly impacts the resources available for sustainability initiatives, potentially leading to disparities in curriculum development, and hindering the incorporation of environmentally conscious content and innovative teaching methods. Moreover, it affects the research landscape, limiting opportunities for groundbreaking studies on sustainable practices and technologies. As a strategic decision reflective of institutional priorities, funding allocation sets the tone for the institution's commitment to sustainability. This economic barrier's interconnected impact with other barriers underscores its significance and emphasizes the need for targeted interventions to address this foundational challenge in the pursuit of sustainable development and decarbonization within higher education.

Figure 7 shows the outcomes of our analysis on political barriers, delineating the following hierarchy of challenges: existing power structures, uncertainty surrounding government funding, government impact on research and teaching, and, finally, a diversity deficit. Notably, our findings underscore the prominence of funding as a substantial political challenge, standing second only to the societal power structures. This insight sheds light on the critical role of financial support in navigating political obstacles, positioning it as a pivotal factor. Moreover, public schools, as government entities, are influenced by the most politically engaged special interest groups, which can hinder efforts to introduce decarbonization initiatives [118]. These findings assist policymakers and researchers by providing actionable insights into addressing power dynamics and financial uncertainties, thus enhancing the efficacy of strategies aimed at fostering inclusivity and overcoming political impediments to sustainable development.

Figure 8 shows the outcomes of personal barriers, offering the following ranked perspective: a scarcity of academic positions, precarity of academic careers, the influence of the status quo, and, finally, students' career ambitions. Crucially, our findings emphasize that the scarcity and precarity of academic careers emerge as key challenges within the realm of personal barriers. This revelation is particularly significant, as it highlights how the challenges associated with academic positions can hinder the willingness to take risks such as altering curricula and pedagogy to decarbonize higher education. Student-related issues have less impact on decarbonization initiatives in higher education institutions [119]. Overcoming these personal barriers involves addressing self-doubt, seeking support, and acquiring the necessary qualifications and knowledge to engage in decarbonization efforts within the academic sector [119]. The imperative for increased research aligned with decarbonization and the incorporation of decarbonization into curricula underscores the significance of tackling these personal barriers to advance decarbonization efforts in higher education.

Figure 9 presents a visual representation of our exploration into social barriers, unveiling a hierarchy that encompasses high carbon behaviors, lack of awareness, institutional constraints linked to staff "buy-in", and, finally, cultural constraints on curricula and pedagogy. A noteworthy revelation from our findings is the explicit identification of the often-criticized academic frequent flyer behavior as a discernible barrier to change within the social context. This observation underscores the significance of addressing unsustainable practices within academia, with a particular emphasis on understanding and addressing cultural influences on curricula and pedagogy.

Individual academic staff can play a pivotal role in inspiring and informing through their teaching, while students can demand and take forward a sustainability focus, underscoring the significance of cultural influences on curricula and pedagogy [120]. Furthermore, the influence of neoliberal paradigms in academia and the need to address and disrupt the embedded culture of neoliberal economization within higher education have been emphasized [121]. The inclusion of cultural constraints highlights our commitment to providing a more comprehensive analysis, recognizing that cultural factors deeply shape and perpetuate certain high carbon behaviors within the academic community. By going into the cultural dimensions of these social barriers, we aim to contribute to a more nuanced understanding of the interconnected challenges in fostering sustainability and decarbonization within higher education.

The concise yet impactful nature of these results provides empirically robust insights into the complex interplay of social factors impeding efforts to decarbonize higher education. By pinpointing specific challenges like high carbon behaviors and institutional constraints, this research equips stakeholders, policymakers, and educators with actionable knowledge to foster a more sustainable and responsive academic environment. The identification of academic frequent flyer behavior as a barrier highlights the need for targeted interventions to address practices that contradict sustainability goals, making this research particularly relevant for the ongoing discourse on transformative change within educational institutions.

Figure 10 visually captures our results for administrative barriers, outlining a hierarchy that includes institutional regulations, the "first mover" penalty, the energy intensiveness of curricula content, and, finally, the necessity for course accreditation. Institutional regulations can pose a barrier to decarbonization efforts. These regulations may not prioritize or mandate the integration of sustainable practices into academic activities, creating a challenge for those seeking to implement decarbonization initiatives [115]. The inclusion of institutional regulations acknowledges the logistical complexities that often impede swift changes in pedagogy.

The "first mover" penalty insight sheds light on the cautious approach of institutions, rooted in concerns about unforeseen consequences and the potential for non-alignment with evolving standards. The challenges of decarbonizing the public sector can provide insights into the measures that could help educational institutions decarbonize their operations and become more sustainable [122].

Additionally, recognizing the energy intensiveness of curriculum content highlights the real-world constraints institutions face, balancing sustainability goals with existing budgetary and resource limitations. The emphasis on course accreditation underscores the institutional commitment to meeting external benchmarks, showcasing the challenges associated with navigating accreditation requirements while simultaneously fostering innovative educational practices.

In essence, Figure 10 provides a comprehensive visual representation of the multifaceted administrative barriers, offering valuable insights into the motivations behind institutional hesitancy and resistance to transformative changes in higher education. This holistic perspective allows for a nuanced understanding of the intricate challenges institutions encounter in navigating these administrative barriers to promote sustainability and decarbonization.

These findings are particularly significant for policymakers, educational administrators, and stakeholders, as they shed light on the dynamics of institutional reluctance and the associated concerns regarding potential penalties. By addressing these administrative barriers, educators and decision-makers can develop strategies to facilitate a more adaptive and sustainable approach to curricula and pedagogy, thereby advancing the broader goals of decarbonizing higher education.

Figure 11 delineates student barriers, presenting a ranking that encompasses job market pressures, insufficient preparedness for course materials, student familiarity with assessment types, and, finally, the perceived inconvenience associated with change. The decarbonization of the economy is creating new jobs, causing some job losses, and changing the skills composition of many jobs. This transition necessitates a good mix of foundational, technical, and core skills for the green economy, requiring upskilling, reskilling, and career guidance to mitigate the risks of job loss [123].

Additionally, the shift to green technology may not absorb many workers displaced by the transition, leading to potential job market challenges for students in affected sectors [124]. These factors contribute to the complex job market pressures that students may encounter as they navigate the evolving landscape of decarbonization and sustainability. Notably, our findings suggest that while students may be open to change, concerns about job market pressures act as a significant deterrent to supporting transformative initiatives. This insight emphasizes the importance of addressing students' apprehensions related to employment uncertainties to foster greater acceptance and engagement in initiatives promoting sustainability and decarbonization.

This research holds relevance for educators, policymakers, and stakeholders aiming to implement changes in higher education, as it underscores the pivotal role of student perspectives and concerns. The acknowledgment of overlapping categories, such as job market pressures being intertwined with economic barriers, reinforces the comprehensive nature of the identified challenges. The recognition of economic conditions as the largest category of barriers, pervasive across various facets, further solidifies the significance of addressing financial considerations in the pursuit of sustainable educational change. This nuanced understanding enhances the practical implications of the research and its potential impact on informed decision-making within the academic realm.

4.2. Opportunities

Figure 12 encapsulates the findings related to opportunities for decarbonizing higher education, presenting a ranked list that includes the evolution of societal norms, diversification of funded subjects, collaboration, reduced precarity of academic employment, student feedback, advances in learning, and, finally, the divestment movement.

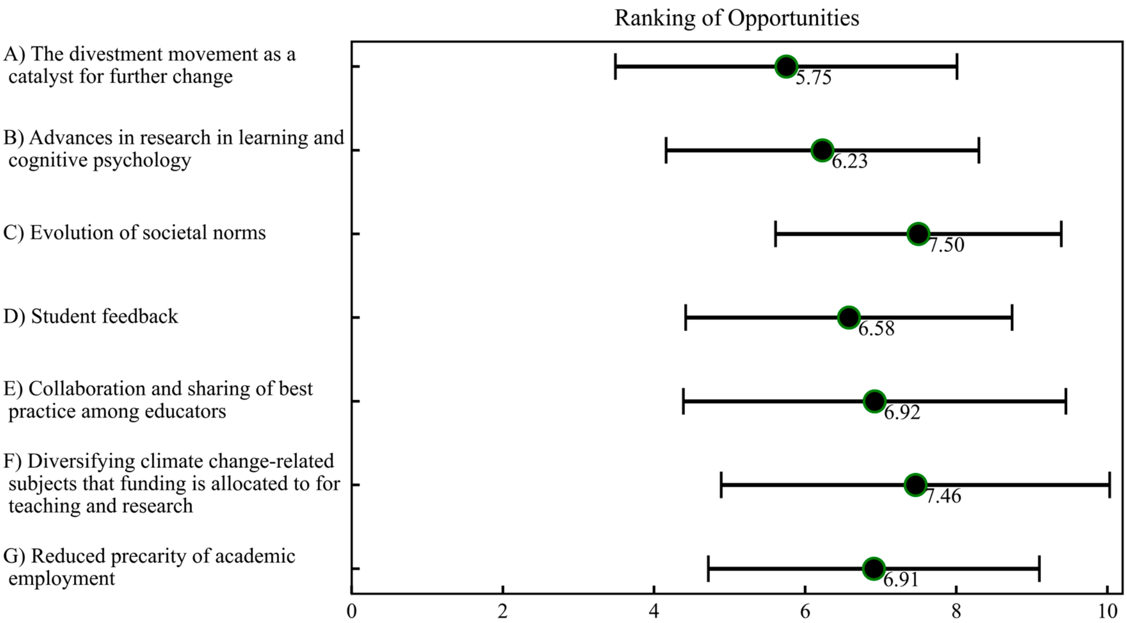

Figure 12. Mean ranking and standard deviation of opportunities for decarbonizing higher education. The highest is 10, while 1 is the lowest.

Societal norms that can impact decarbonization efforts in higher education, such as attitudes toward sustainability, resource use, and climate change, have been a focal point in previous studies [125]. Higher education institutions, as social institutions, are influenced by societal perspectives on environmental responsibility and sustainable development [114]. The current study aligns with these prior findings, highlighting the continuing significance of societal norms in shaping the commitment of higher education institutions to decarbonization.

The COVID-19 pandemic has also affected cultural, societal, and institutional norms, leading to changes in campus operations and potentially influencing attitudes toward decarbonization [126]. The broader societal shifts indicated in the findings align with the observed impacts of the pandemic on higher education. The pandemic has exacerbated existing disparities and inequities in education, with evidence showing that it has negatively affected academic growth and widened pre-existing disparities, particularly for students from historically marginalized and underserved groups [127].

Additionally, the readiness of the community and governance structures within universities, as well as the attitudes of campus stakeholders, can shape the effectiveness of decarbonization efforts [125]. Furthermore, assessing the status of decarbonization efforts at universities within a 2050 perspective and understanding the prevailing attitudes toward decarbonization among campus stakeholders can help in addressing societal norms in decarbonization efforts [119].

By expanding the scope of climate change education and research, universities can better address the multifaceted challenges associated with climate change. This can involve engaging in a broader range of disciplines and contexts, thereby leveraging the comprehensive body of information and experience within universities to contribute significantly to addressing climate change challenges [128]. Additionally, diversifying climate change-related subjects can contribute to the promotion of sustainable development and the training of professionals to meet the global need for addressing climate change. Therefore, by allocating funding to a wider array of climate change-related subjects, higher education institutions can play a crucial role in advancing decarbonization efforts and sustainability.

In essence, our results, when considered in conjunction with the existing literature, contribute to a more comprehensive understanding of the complex interplay between societal norms and decarbonization efforts in higher education. These results suggest that academia is poised to evolve in tandem with societal changes rather than taking the lead, a phenomenon that may challenge the self-perception of universities as being at the "cutting edge" of knowledge creation and dissemination. Additionally, the recurring theme of the pivotal role of funding is once again underscored.

5. Discussion

The rankings of barrier categories undergo notable shifts when comparing the high-level and more granular perspectives. At the macro level, the "Economic" category takes precedence as the most significant barrier, only to be supplanted by other factors at the detailed level, where it assumes a third-place ranking. Similarly, the "Social" barriers, initially placed fourth in the overarching view, ascend to claim the top spot in the nuanced breakdown.

Observing the categories of "Administrative", "Personal", and "Political", one notices perceptible changes in their perceived significance between the two levels of analysis. Intriguingly, the "Student" category remains a constant, consistently occupying the position of least significant barrier in both perspectives. These variations might stem from respondent demographics or the inherent difference in granularity, indicating that perceptions differ when evaluating barriers broadly versus in specific instances within each category.

Noteworthy among our findings is the prominence of "Social" barriers, emerging as the foremost concern among respondents, reflected in the highest average mean score of approximately 6.75. This underscores the consensus that challenges rooted in societal norms and interactions are substantial impediments. In contrast, barriers linked to "Students" are perceived as comparatively less pressing, garnering the lowest average mean score of around 5.44.

Results indicate a striking diversity of opinions regarding specific barriers, with political barriers standing out for their considerable variability in mean scores. This variability likely arises from the intricate nature of political challenges, spanning issues like government funding and institutional hierarchies. In contrast, administrative barriers present a more consensual perspective among respondents, showcasing the least variability in mean scores.

One barrier, namely "Existing power structures and power dynamics in society" (political barrier C), attains the highest mean score of 7.36. This underscores respondents' perception that challenges in academia are intricately intertwined with broader societal structures. The influence of power dynamics in society extends to decision-making, policy formulation, funding allocation, and public opinion—all of which reverberate within academia. The manifestation of societal resistance in academia could manifest as a lack of funding, support, or public trust in initiatives addressing societal challenges. Tackling such a barrier may necessitate an interdisciplinary approach, fostering collaboration across academic fields and engaging external stakeholders to comprehend and navigate the intricate web of societal power dynamics.

Furthermore, the barrier related to the "Inadequacy and uncertainty of government funding" also garners a high mean score of 7.31 (political barrier B). The critical role of funding in research, teaching, and various academic pursuits makes uncertainty or inadequacy in government funding a significant hindrance, particularly for initiatives addressing new challenges like decarbonization in academia. This concern is closely tied to the top-rated barrier concerning existing power structures, indicating a symbiotic relationship between societal power dynamics and financial support for academic endeavors.

Despite the lower mean scores associated with barriers linked to student preferences and behaviors, there exists substantial variability in perceptions, indicating a spectrum of opinions on these issues. Notably, the standard deviations for barriers related to student behaviors and preferences are relatively high, emphasizing the diverse perspectives within the respondent pool. For instance, student barrier (A) stands out with the highest standard deviation of 2.89, suggesting that while some respondents perceive it as a significant obstacle, others may not, resulting in a wide range of scores. Meanwhile, student barriers (B), (C), and (D) rank towards the lower end of the responses, underscoring the varied opinions on these matters and highlighting the intricate nature of addressing challenges centered around students.

Investigating the response counts further, it becomes evident that Administrative and Personal barriers resonate with a broader audience, receiving feedback from nearly all respondents. This widespread recognition suggests that these challenges are either widely experienced or widely acknowledged within the academic community. The universality of these concerns underscores their significance and emphasizes the need for comprehensive strategies to address them effectively, considering their pervasive impact across the academic landscape.

Feedback counts demonstrate variability across barriers, implying differences in relevance or familiarity among respondents. Barriers such as "Inadequacy and uncertainty of government funding" (political B), "Lack of teaching resources and staff" (economic B), and "Institutional regulations regarding pedagogical practice" (administrative B) each garnered feedback from 26 respondents, suggesting widespread recognition or experience of these challenges within the academic community. On the contrary, the barrier "Lack of diversity (race, gender, nationality, etc.) in academia" (political A) received feedback from only 19 respondents. This does not diminish the importance of political A but may indicate that fewer respondents felt prepared or inclined to rate it based on their experiences or perceptions.

Regarding opportunities, the evolution of societal norms emerges as the most significant, emphasizing the profound influence of broader societal shifts on academic landscapes. Additionally, there is a prevailing sentiment toward diversifying academic subjects related to climate change and fostering collaboration among academics, highlighting the value of interdisciplinary approaches and shared best practices. While certain areas, such as the divestment movement in universities, elicit more varied opinions, there is a consensus favoring the transformative potential inherent in embracing societal changes and collaborative endeavors in academia. This collective perspective underscores the importance of adaptability and collaboration to address contemporary challenges in academia.

As we explore the potential opportunities revealed by the survey results, it is crucial to recognize the nuanced nature of implementing changes across diverse academic disciplines and institutions. While the pursuit of sustainability in higher education is widely acknowledged as beneficial, it is equally important to critically examine the potential challenges, trade-offs, and inherent complexities associated with these changes. The academic landscape is multifaceted, encompassing a broad spectrum of disciplines, institutional structures, and regional disparities. A one-size-fits-all approach may not suffice, and a tailored strategy that considers the unique characteristics of different academic settings becomes imperative.

The diverse nature of academic disciplines introduces varied perspectives, methodologies, and priorities, necessitating a careful consideration of disciplinary nuances in any sustainability initiative. Similarly, the structural differences between institutions, ranging from small liberal arts colleges to large research universities, require adaptable strategies. Regional disparities, influenced by cultural, economic, and geographical factors, further contribute to the complexity of fostering sustainability in higher education.

6. Conclusions

At the highest level, the largest category of barriers emerging from these results are economic barriers, followed by administrative barriers. Personal, social, political, and student related barriers are considered less pressing, but regardless should still be addressed, in this order.

Within economic barriers, the allocation of funding and the lack of resources and staff are the largest issues. The overlap of economic barriers with other categories has been noted, indeed with economic barriers appearing rather ubiquitous. Therefore, finding greater sources of funding for teaching (and research), in addition to diversifying existing funding sources is the most essential decarbonization step that academic institutions must take. They should be aided in these attempts by both governments and private sources of funding (whilst remaining mindful of the role of fossil fuel-related funding).

However, it should be noted that the three highest scoring individual barriers are political (C and B) and social (A). This suggests a disconnect between how respondents think about “high level” barriers compared to specific examples. Political barriers, especially those related to power dynamics and government funding, are perceived as some of the most significant challenges.

With regards to administrative barriers, institutional regulations are seen as the biggest obstacle to curriculum and pedagogical change, along with “first mover” penalties, suggesting universities consider that they will be penalized somehow for changing their curricula or pedagogies. The onus is therefore on institutions to recognize that they must change and that the processes for enabling change must be improved.

In terms of incorporating sustainability and climate change into curricula, it is recommended that these themes be woven throughout courses, indeed seen as an integral part of existing courses rather than a supplement. However, the route forward for pedagogy is less clear.

Concerning future work, we believe developing a roadmap in each of the barrier areas identified to be an essential next step. We have uncovered a list of priorities in this work which should be investigated further. Furthermore, research endeavors could explore the integration of a broader spectrum of SDGs into academic initiatives, considering their interconnectedness and the need for a comprehensive approach to sustainable development. If universities wish to be seen as to lead in combatting climate change, acting on the areas described in the order of priority uncovered is essential.

Author Contributions: Writing—original draft and visualization, D.A.K.; Methodology, formal analysis, writing—original draft, and visualization, C.L.; Writing—review and editing, supervising, and funding acquisition, A.F. All authors have read and agreed to the published version of the manuscript.

Funding: Dlzar Al Kez, Christopher Lowans, and Aoife Foley’s research is supported by HM Treasury, the Department for the Economy (DfE), and the Engineering and Physical Sciences Research Council (EPSRC). The views and opinions expressed in this document do not necessarily reflect those of HM Treasury, the DfE and the EPSRC.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data will be made available on request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Times Higher Education Impact Ranking. Available online: https://www.timeshighereducation.com/impactrankings (accessed on 12 June 2023).
2. McGeown, C.; Barry, J. Agents of (Un)Sustainability: Democratising Universities for the Planetary Crisis. *Front. Sustain.* **2023**, *4*, 1166642. [CrossRef]
3. Ferguson, T.; Roofe, C.; Cook, L.D.; Bramwell-Lalor, S.; Hordatt Gentles, C. Education for Sustainable Development (ESD) Infusion into Curricula: Influences on Students' Understandings of Sustainable Development and ESD. *Brock Educ. J.* **2022**, *31*, 63–84. [CrossRef]
4. Tang, K.H.D. A Model of Behavioral Climate Change Education for Higher Educational Institutions. *Environ. Adv.* **2022**, *9*, 100305. [CrossRef]
5. Builes Vélez, A.E.; Builes Escobar, N.; Rossi, E.; Mattram, A.; Stocker, J.; Rognoli, V.; Parisi, S.; Pollini, B.; Taranto, M.; Amaya-García, C.; et al. *Education for Sustainability Approaching SDG 4 and Target 4.7*; Pontifical Bolivarian University: Medellín, Colombia, 2022; ISBN 9786285000775.
6. Jiang, Q.; Kurnitski, J. Performance Based Core Sustainability Metrics for University Campuses Developing towards Climate Neutrality: A Robust PICSOU Framework. *Sustain. Cities Soc.* **2023**, *97*, 104723. [CrossRef]
7. Chaplin, G.; Dibaj, M.; Akrami, M. Decarbonising Universities: Case Study of the University of Exeter's Green Strategy Plans Based on Analysing Its Energy Demand in 2012–2020. *Sustainability* **2022**, *14*, 4085. [CrossRef]
8. Ozawa-Meida, L.; Brockway, P.; Letten, K.; Davies, J.; Fleming, P. Measuring Carbon Performance in a UK University through a Consumption-Based Carbon Footprint: De Montfort University Case Study. *J. Clean. Prod.* **2013**, *56*, 185–198. [CrossRef]
9. Jaglan, A.K.; Cheela, V.R.S.; Vinaik, M.; Dubey, B. Environmental Impact Evaluation of University Integrated Waste Management System in India Using Life Cycle Analysis. *Sustainability* **2022**, *14*, 8361. [CrossRef]
10. Laurie, R.; Nonoyama-Tarumi, Y.; Mckeown, R.; Hopkins, C. Contributions of Education for Sustainable Development (ESD) to Quality Education: A Synthesis of Research. *J. Educ. Sustain. Dev.* **2016**, *10*, 226–242. [CrossRef]
11. Adrian, P.; Andy, B.A.S.; Anna, D.; Cheikh, M.; Olav, H.D.; Salmi, B.N.H.J.; Melody, B.B.; Seeram, R.; Sol, S.; Sylvia, S.; et al. *Knowledge-Driven Actions: Transforming Higher Education for Global Sustainability*; United Nations Educational, Scientific and Cultural Organization: Paris, France, 2022.
12. Kinol, A.; Miller, E.; Axtell, H.; Hirschfeld, I.; Leggett, S.; Si, Y.; Stephens, J.C. Climate Justice in Higher Education: A Proposed Paradigm Shift towards a Transformative Role for Colleges and Universities. *Clim. Change* **2023**, *176*, 15. [CrossRef]
13. Gamoran, A. The Future of Higher Education Is Social Impact. Available online: https://ssir.org/articles/entry/the_future_of_higher_education_is_social_impact (accessed on 30 November 2023).
14. Heffron, R.; Foley, A. Promote Clean-Energy Transition in Student Education. *Nature* **2022**, *607*, 103–106. [CrossRef]
15. Barbosa Soares, C.A.; De Nadae, J.; Do Nascimento, D.C.; Alves Firmino, P.R.; Morioka, S.N. Photovoltaic Solar Energy and Sustainability in Higher Education Institutions: A Multiple Case Study. *J. Sustain. Prod. Oper. Syst. Manag.* **2023**, *18*, e02939. [CrossRef]
16. Martínez-Acosta, M.; Vázquez-Villegas, P.; Mejía-Manzano, L.A.; Soto-Inzunza, G.V.; Ruiz-Aguilar, K.M.; Kuhn Cuellar, L.; Caratozzolo, P.; Membrillo-Hernández, J. The Implementation of SDG12 in and from Higher Education Institutions: Universities as Laboratories for Generating Sustainable Cities. *Front. Sustain. Cities* **2023**, *5*, 1158464. [CrossRef]
17. Leahy, P.G.; Sovacool, B.K. Decarbonize Pedagogy—Apply Sustainable Development Goals. *Nature* **2022**, *608*, 266. [CrossRef]
18. Guerola-navarro, V.; Gil-gomez, H.; Botella-Carrubí, D.; Gil-Gomez, J.-A. Evaluation of the Knowledge and Commitment That Students of a University Subject Focused on Organizational Behavior Have on the Sustainable Development Goals (SDGs), with the Aim of Increasing the Link between University Teaching and the SDGs. In Proceedings of the International Conference on Innovation, Documentation and Education INNODOCT/22, Valencia, Spain, 2–7 November 2022; pp. 29–36.
19. Mohd Noor, Z.; Mustafa, M.; Mohd Said, R. Mapping of Sdgs in the Engineering and Computer Science Curriculum At Universiti Teknologi Mara. *Malaysian J. Sport Sci. Recreat.* **2023**, *19*, 196–204. [CrossRef]
20. Maharjan, N.; Kuroda, K.; Silwal, G.; Toyama, S.; Ominato, Y.; Tsuchida, Y. Implementation of Design Based Learning for the Development of SDGs Educational Games. *J. Technol. Sci. Educ.* **2022**, *12*, 496–509. [CrossRef]
21. Kashah, E. Pedagogical Apparatus of a Textbook. Text and Methodical Work with It, Class Time and Forms of Its Organization. *Br. J. Multidiscip. Adv. Stud.* **2023**, *4*, 68–78. [CrossRef]
22. Arnold, K.-H. Didactics, Didactic Models and Learning. In *Encyclopedia of the Sciences of Learning*; Seel, N.M., Ed.; Springer: Boston, MA, USA, 2012; pp. 986–990.
23. Instance, D.; Paniagua, A.; Winthrop, R.; Ziegler, L. *Learning to Leapfrog: Innovative Pedagogies to Transform Education Policy Brief Summary Findings*; Center for Universal Education at The Brookings Institution: Washington, DC, USA, 2019.
24. Halder, I. Innovation Pedagogy of 21st Century: Challenges and Opportunities. *Int. J. Multidiscip. Res.* **2023**, *5*, 1–6. [CrossRef]

25. Leat, D.; Whelan, A. Innovative Pedagogies in Relation to Curriculum. In *International Encyclopedia of Education*; Tierne, R.J., Rizvi, F., Ercikan, K., Eds.; Elsevier: Amsterdam, The Netherlands, 2023; pp. 132–141.
26. Chigbu, B.I.; Ngwevu, V.; Jojo, A. The Effectiveness of Innovative Pedagogy in the Industry 4.0: Educational Ecosystem Perspective. *Soc. Sci. Humanit. Open* **2023**, *7*, 100419. [CrossRef]
27. Zhang, J.; Yu, S. Assessing the Innovation of Mobile Pedagogy from the Teacher's Perspective. *Sustainability* **2022**, *14*, 15676. [CrossRef]
28. Sabbagh, C. Pedagogies. In *Socializing Justice: The Role of Formal, Non-Formal, and Family Education Spheres*; Oxford Academic: New York, NY, USA, 2022.
29. Srinivasa, K.G.; Kurni, M.; Saritha, K. Learning, Teaching, and Assessment Methods for Contemporary Learners. In *Springer Texts in Education*; Springer: Singapore, 2022; pp. 1–15.
30. Paniagua, A.; Istance, D. *Teachers as Designers of Learning Environments: The Importance of Innovative Pedagogies*; OECD Publishing: Paris, France, 2018.
31. Merino, A.; Díaz, E. Transforming Ourselves to Transform Societies: Cultivating Virtue in Higher Education for Sustainability. In *The Wiley Handbook of Sustainability in Higher Education Learning and Teaching*; Gamage, K.A.A., Gunawardhana, N., Eds.; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2022.
32. Ellyatt, W. Education for Human Flourishing—A New Conceptual Framework for Promoting Ecosystemic Wellbeing in Schools. *Challenges* **2022**, *13*, 58. [CrossRef]
33. Verheijen, L. Matters of Measuring: Student Learning and Success in Sustainability Education. In *Business Schools, Leadership and the Sustainable Development Goals*; Moratis, L., Melissen, F., Eds.; Routledge: New York, NY, USA, 2022.
34. European Centre for the Development of Vocational Training (CEPEF Learning Outcomes). Available online: https://www.cedefop.europa.eu/en/projects/learning-outcomes (accessed on 29 December 2023).
35. Riaz, A.; Rahman, M.S. *Routledge Handbook of Contemporary Bangladesh*, 1st ed.; Routledge: London, UK, 2016.
36. University and College Union Decarbonise and Decolonise 2030. UCU's Model Claim for Universities and Colleges. Available online: https://www.ucu.org.uk/media/11652/Decarbonise--decolonise-presentation/pdf/D_D2030_presentation.pdf (accessed on 20 January 2023).
37. University and College Union COP26 CAMPAIGN. Decarbonise and Decolonise 2030. Available online: https://www.ucu.org.uk/media/11630/COP26-campaign-decarbonise-and-decolonise-2030---quick-guide/pdf/Decarbonise_Decolonise_quick_guide_Jun21.pdf (accessed on 2 May 2023).
38. Robins, N.; Rydge, J. *Why a Just Transition Is Crucial for Effective Climate Action*; Vivid Economics Limited: London, UK, 2019.
39. Mary Robinson Foundation Mary Robinson Foundation—Climate Justice | Principles of Climate Justice. Available online: https://www.mrfcj.org/principles-of-climate-justice/ (accessed on 15 February 2023).
40. Energy Systems Catapult The School Decarbonisation Challenge. An Exploratory Study on Behalf of the Department for Education. Available online: https://es.catapult.org.uk/report/the-school-decarbonisation-challenge/ (accessed on 7 February 2023).
41. Weinstein, Y.; Madan, C.R.; Sumeracki, M.A. Teaching the Science of Learning. *Cogn. Res. Princ. Implic.* **2018**, *3*, 2. [CrossRef]
42. Agarwal, P.K.; Roediger, H.L. Lessons for Learning: How Cognitive Psychology Informs Classroom Practice. *Phi Delta Kappan* **2018**, *100*, 8–12. [CrossRef]
43. The Learning Scientists Episode 12-Dual Coding. Available online: https://www.learningscientists.org/learning-scientists-podcast/2018/2/7/episode-12-dual-coding (accessed on 31 December 2023).
44. Forbus, K.D.; Uttal, D. Technologies for Spatial Learning. In *Developing Minds in the Digital Age: Towards a Science of Learning for 21st Century Education*; Kuhl, P.K., Lim, S.-S., Guerrieroiii, S., Van Damme, D., Eds.; OECDiLibrary: Berlin, Germany, 2019; pp. 1–260.
45. Nebel, C. Considerations for Applying Six Strategies for Effective Learning to Instruction. *Med. Sci. Educ.* **2020**, *30*, 9–10. [CrossRef]
46. Hartwig, M.K.; Rohrer, D. Interleaved Practice Improves Mathematics Learning. Available online: https://researchingeducation.com/hartwig_rohrer/ (accessed on 31 December 2023).
47. Madan, C.R. Using Evidence-Based Learning Strategies to Improve Medical Education. *Med. Sci. Educ.* **2023**, *33*, 773–776. [CrossRef]
48. Friedlander, M.J.; Andrews, L.; Armstrong, E.G.; Aschenbrenner, C.; Kass, J.S.; Ogden, P.; Schwartzstein, R.; Viggiano, T.R. What Can Medical Education Learn from the Neurobiology of Learning? *Acad. Med.* **2011**, *86*, 415–420. [CrossRef] [PubMed]
49. Dubinsky, J.M.; Guzey, S.S.; Schwartz, M.S.; Roehrig, G.; MacNabb, C.; Schmied, A.; Hinesley, V.; Hoelscher, M.; Michlin, M.; Schmitt, L.; et al. Contributions of Neuroscience Knowledge to Teachers and Their Practice. *Neuroscientist* **2019**, *25*, 394–407. [CrossRef] [PubMed]
50. Robertson, L.T. Memory and the Brain. *J. Dent. Educ.* **2002**, *66*, 30–42. [CrossRef]
51. Nong, W.; Ye, J.H.; Chen, P.; Lee, Y.S. A Study on the Blended Learning Effects on Students Majoring in Preschool Education in the Post-Pandemic Era: An Example of a Research-Method Course in a Chinese University. *Front. Psychol.* **2023**, *13*, 962707. [CrossRef] [PubMed]
52. Grimes, N. Educational Technology and the Pre-K-12 Environment. In *Encyclopedia of Information Science and Technology*; Mehdi Khosrow-Pour, D.B.A., Ed.; IGI Global: Hershey, PA, USA, 2024; pp. 1–21.

53. Charles, A.; Yomboi, J.; Arko-Cole, N.; Tijani, A. Emerging Use of Technologies in Education. In *Digital Transformation in Education: Emerging Markets and Opportunities*; IGI Global: Hershey, PA, USA, 2023; pp. 1–82.
54. Manzano Pérez, R.S.; López Pérez, T.E.; Manzano Pérez, R.J.; Pérez López, M.V. Technological Innovation and Education: A Brief Review of the Literature. *Ibero-Am. J. Educ. Soc. Res.* **2023**, *3*, 25–30. [CrossRef]
55. Velayutham, G.; Raja, A.; Chalke, D.F.J. Impact of New Technologies in Education. *J. Pharm. Negat. Results* **2022**, *13*, 1393–1396. [CrossRef]
56. Tech & Learning Study:, U.S. Teachers Lacking in Tech Training. Available online: https://www.techlearning.com/ed-tech-ticker/12427 (accessed on 31 December 2023).
57. Google for Education Emerging Technologies. Available online: https://edu.google.com/intl/ALL_us/future-of-the-classroom/emerging-technologies/ (accessed on 31 December 2023).
58. Trust Digital Technologies Are Having a Positive Impact on Student Achievement. Available online: https://2020.org.nz/wp-content/uploads/2014/05/digital-technologies-in-schools-2017_report.pdf (accessed on 31 December 2023).
59. Dick, E. *The Promise of Immersive Learning: Augmented and Virtual Reality's Potential in Education*; Information Technology and Innovation Foundation: Washington, DC, USA, 2021.
60. Shankar, A.U.; Tewari, V.; Rahman, M.; Mishra, A.; Bajaj, K.K. Impact of Virtual Reality (Vr) and Augmented Reality (Ar) in Education. *J. Propuls. Technol.* **2023**, *44*, 1310–1318. [CrossRef]
61. Nikou, S.; Aavakare, M. An Assessment of the Interplay between Literacy and Digital Technology in Higher Education. *Educ. Inf. Technol.* **2021**, *26*, 3893–3915. [CrossRef]
62. Al Kez, D.; Foley, A.M. Exploring the Sustainability Challenges Facing Digitalization and Internet Data Centers. *J. Clean. Prod.* **2022**, *371*, 133633. [CrossRef]
63. Flower, F.X.L.L.; Sugirtha, J.T. Education 4.0: Revisiting Contemporary Paradigms in Social Work Education. In *Industry 4.0 Technologies for Education: Transformative Technologies and Applications*; Kaliraj, P., Devi, T., Eds.; Taylor & Francis: New York, NY, USA, 2022; p. 10.
64. Gkrimpizi, T.; Peristeras, V.; Magnisalis, I. Classification of Barriers to Digital Transformation in Higher Education Institutions: Systematic Literature Review. *Educ. Sci.* **2023**, *13*, 746. [CrossRef]
65. Tony Carusi, F.; Szkudlarek, T. Education Is Society. . . and There Is No Society: The Ontological Turn of Education. *Policy Futur. Educ.* **2020**, *18*, 907–921. [CrossRef]
66. Mintz, S. Pedagogy and Course Design Need to Change. Here's How. | Inside Higher Ed. Available online: https://www.insidehighered.com/blogs/higher-ed-gamma/pedagogy-and-course-design-need-change-here%E2%80%99s-how (accessed on 17 February 2023).
67. Reid, P. Categories for Barriers to Adoption of Instructional Technologies. *Educ. Inf. Technol.* **2014**, *19*, 383–407. [CrossRef]
68. Mohamed Hashim, M.A.; Tlemsani, I.; Duncan Matthews, R. A Sustainable University: Digital Transformation and Beyond. *Educ. Inf. Technol.* **2022**, *27*, 8961–8996. [CrossRef] [PubMed]
69. Jetly, M.; Singh, N. Analytical Study Based on Perspectives of Teacher Educators in India with Respect to Education for Sustainable Development. *J. Teach. Educ. Sustain.* **2019**, *21*, 38–55. [CrossRef]
70. Zhukova, O.; Fjodorova, I.; Iliško, D. Novice Teachers' Beliefs and Knowledge about Education for Sustainable Development. *Acta Paedagog. Vilnensia* **2020**, *44*, 34–44. [CrossRef]
71. Kohtamäki, N. The Case of Finnish Innovative Society: Shaping Legal Higher Education in Line with the Ideals of Social Solidarity. *Stud. Eur. Stud. Eur. Aff.* **2023**, *26*, 199–215. [CrossRef]
72. United Nations Mobilizing Science, Technology, and Innovation and Strengthening the Science-Policy-Society Interface. Available online: https://sustainabledevelopment.un.org/content/documents/27892BN_HLPF_2021__Science_technology_and_innovation.pdf (accessed on 1 January 2024).
73. GlobalNewswire E-Learning Market Is Projected to Hit USD 848.12 Billion at a CAGR of 17.54% by 2030—Report by Facts & Factors (FnF). Available online: https://www.globenewswire.com/en/news-release/2023/02/02/2600283/0/en/E-Learning-Market-is-Projected-to-Hit-USD-848-12-Billion-at-a-CAGR-of-17-54-by-2030-Report-by-Facts-Factors-FnF.html (accessed on 1 January 2024).
74. Haughney, K.; Wakeman, S.; Hart, L. Quality of Feedback in Higher Education: A Review of Literature. *Educ. Sci.* **2020**, *10*, 60. [CrossRef]
75. Bravo, J.; Lecca-Orrego, G.; Alarcón, R. Influence of Technological Factors in Teaching and Communication in Higher Education During the COVID-19 Health Crisis. In *Communication and Applied Technologies. Smart Innovation, Systems and Technologies*; López-López, P.C., Barredo, D., Torres-Toukoumidis, Á., De-Santis, A., Avilés, Ó., Eds.; Springer: Singapore, 2023; ISBN 9789811963469.
76. Sadler, D.R. Beyond Feedback: Developing Student Capability in Complex Appraisal. *Assess. Eval. High. Educ.* **2010**, *35*, 535–550. [CrossRef]
77. Worsham, M.; Brecha, R.J. Carbon Lock-in: An Obstacle in Higher Education's Decarbonization Pathways. *J. Environ. Stud. Sci.* **2017**, *7*, 435–449. [CrossRef]
78. Biresselioglu, M.E.; Demir, M.H.; Demirbag Kaplan, M.; Solak, B. Individuals, Collectives, and Energy Transition: Analysing the Motivators and Barriers of European Decarbonisation. *Energy Res. Soc. Sci.* **2020**, *66*, 101493. [CrossRef]

79. McKie, R.E. Obstruction, Delay, and Transnationalism: Examining the Online Climate Change Counter-Movement. *Energy Res. Soc. Sci.* **2021**, *80*, 102217. [CrossRef]
80. Ladd, A.E. Priming the Well: "Frackademia" and the Corporate Pipeline of Oil and Gas Funding into Higher Education. *Humanity Soc.* **2020**, *44*, 151–177. [CrossRef]
81. Horton, H. 100 UK Universities Pledge to Divest from Fossil Fuels. Available online: https://www.theguardian.com/education/2022/oct/27/uk-universities-divest-fossil-fuels (accessed on 27 October 2023).
82. Baron, R.; Fischer, D. *Divestment and Stranded Assets in the Low-Carbon Transition*; OECD Publishing: Paris, France, 2015.
83. Federal Reserve Bank of Dallas. Oil and Gas Activity Jumps; Costs Escalate, Supply-Chain Delays Worsen. Available online: https://www.dallasfed.org/research/surveys/des/2022/2202 (accessed on 22 February 2023).
84. Bolton, P. *Higher Education Funding in England*; House of Commons Library: London, UK, 2021.
85. Overland, I.; Sovacool, B.K. The Misallocation of Climate Research Funding. *Energy Res. Soc. Sci.* **2020**, *62*, 101349. [CrossRef]
86. Stephens, J.C. Diversifying Power. Available online: https://islandpress.org/books/diversifying-power (accessed on 15 February 2023).
87. Jones, G.A.; Shanahan, T.; Goyan, P. Traditional Governance Structures—Current Policy Pressures: The Academic Senate and Canadian Universities. *Tert. Educ. Manag.* **2010**, *8*, 29–45. [CrossRef]
88. Palamountain, J.C. Power Structures in the University. *Antioch Rev.* **1966**, *26*, 299–306. [CrossRef]
89. Weerts, D.J.; Ronca, J.M. Examining Differences in State Support for Higher Education: A Comparative Study of State Appropriations for Research I Universities. *J. Higher Educ.* **2006**, *77*, 935–967. [CrossRef]
90. Pinar, W.F.; Reynolds, W.M.; Slattery, P.; Taubman, P.M. Chapter 5: Understanding Curriculum as Political Text. *Counterpoints* **1995**, *17*, 243–314.
91. Dunne, T.; Kurki, M.; Smith, S. *International Relations Theories: Discipline and Diversity*, 5th ed.; Oxford University Press: Oxford, UK, 2020; ISBN 9780198814443.
92. Wahlström, N. Where Is 'the Political' in Curriculum Research? *J. Curric. Stud.* **2018**, *50*, 711–723. [CrossRef]
93. Jordan, A.; Lorenzoni, I.; Tosun, J.; i Sausi, J.E.; Geese, L.; Kenny, J.; Saad, E.L.; Moore, B.; Schaub, S.G. The Political Challenges of Deep Decarbonisation: Towards a More Integrated Agenda. *Clim. Action* **2022**, *1*, 6. [CrossRef]
94. Schulze, K. Policy Characteristics, Electoral Cycles, and the Partisan Politics of Climate Change. *Glob. Environ. Polit.* **2021**, *21*, 44–72. [CrossRef]
95. Giddens, A. *The Politics of Climate Change*; Policy Network: London, UK, 2008.
96. Jost, J.T. *A Theory of System Justification*; Harvard University Press: Harvard, MA, USA, 2020; ISBN 9780674244658.
97. The Royal Society. *The Scientific Century: Securing Our Future Prosperity*; Royal Society: London, UK, 2020.
98. Bhardwa, S. Why Do Students Go to University and How Do They Choose Which One? Available online: https://www.timeshighereducation.com/student/news/why-do-students-go-university-and-how-do-they-choose-which-one (accessed on 22 February 2023).
99. Dobruszkes, F.; Mattioli, G.; Mathieu, L. Banning Super Short-Haul Flights: Environmental Evidence or Political Turbulence? *J. Transp. Geogr.* **2022**, *104*, 103457. [CrossRef]
100. Higham, J.; Font, X. Decarbonising Academia: Confronting Our Climate Hypocrisy. *J. Sustain. Tour.* **2020**, *28*, 1–9. [CrossRef]
101. Squire, K.D.; MaKinster, J.G.; Barnett, M.; Luehmann, A.L.; Barab, S.L. Designed Curriculum and Local Culture: Acknowledging the Primacy of Classroom Culture. *Sci. Educ.* **2003**, *87*, 468–489. [CrossRef]
102. Morreira, S.; Luckett, K.; Kumalo, S.H.; Ramgotra, M. Confronting the Complexities of Decolonising Curricula and Pedagogy in Higher Education. *Third World Themat. A TWQ J.* **2020**, *5*, 1–18. [CrossRef]
103. Kim, J. Are Academic Careers Compatible With Achieving Work-Life Balance? Available online: https://www.insidehighered.com/blogs/learning-innovation/are-academic-careers-compatible-achieving-work-life-balance (accessed on 17 May 2023).
104. Institution of Mechanical Engineers How Do I Get My University Academic Programme Accredited—IMechE. Available online: https://www.imeche.org/membership-registration/support-for-universities/how-do-i-get-my-university-accredited (accessed on 23 February 2023).
105. Graham, L.; Williams, L.; Chisoro, C. Barriers to the Labour Market for Unemployed Graduates in South Africa. *J. Educ. Work* **2019**, *32*, 360–376. [CrossRef]
106. Pearson, R. The Changing Graduate Labour Market. *Nature* **1986**, *324*, 94. [CrossRef]
107. Bailey, M.A.; Rosenthal, J.S.; Yoon, A.H. Grades and Incentives: Assessing Competing Grade Point Average Measures and Postgraduate Outcomes. *Stud. High. Educ.* **2016**, *41*, 1548–1562. [CrossRef]
108. Jones, H. Are Our Students Prepared for University? *Biosci. Educ.* **2011**, *18*, 1–12. [CrossRef]
109. Coffey, Y.; Bhullar, N.; Durkin, J.; Islam, M.S.; Usher, K. Understanding Eco-Anxiety: A Systematic Scoping Review of Current Literature and Identified Knowledge Gaps. *J. Clim. Change Health* **2021**, *3*, 100047. [CrossRef]
110. Debnath, R.; van der Linden, S.; Alvarez, R.M.; Sovacool, B.K. Facilitating System-Level Behavioural Climate Action Using Computational Social Science. *Nat. Hum. Behav.* **2023**, *7*, 155–156. [CrossRef]
111. Martin, A.J.; Collie, R.J.; Nagy, R.P. Adaptability and High School Students' Online Learning During COVID-19: A Job Demands-Resources Perspective. *Front. Psychol.* **2021**, *12*, 702163. [CrossRef] [PubMed]
112. Sovacool, B.K.; Martiskainen, M.; Furszyfer Del Rio, D.D. Knowledge, Energy Sustainability, and Vulnerability in the Demographics of Smart Home Technology Diffusion. *Energy Policy* **2021**, *153*, 112196. [CrossRef]

113. Vidal, J. Move to Drop Debate on Climate Change in Schools Faces Backlash. Available online: https://www.theguardian.com/environment/2013/mar/18/climate-change-schools-backlash (accessed on 22 February 2023).
114. da Silva, L.A.; de Aguiar Dutra, A.R.; de Andrade Guerra, J.B.S.O. Decarbonization in Higher Education Institutions as a Way to Achieve a Green Campus: A Literature Review. *Sustainability* **2023**, *15*, 4043. [CrossRef]
115. Reyes-García, V.; Graf, L.; Junqueira, A.B.; Madrid, C. Decarbonizing the Academic Sector: Lessons from an International Research Project. *J. Clean. Prod.* **2022**, *368*, 133174. [CrossRef]
116. Bernstein, S.; Hoffmann, M. The Politics of Decarbonization and the Catalytic Impact of Subnational Climate Experiments. *Policy Sci.* **2018**, *51*, 189–211. [CrossRef] [PubMed]
117. Rodriguez, A.D.; Cohen, D.A.; Kitzmiller, E.; McDonald, K.; Backer, D.I.; Shah, N.; Gavigan, I.; Xan Lillehei, A.L.M.; Gault, A.-J.; Glasser, E.; et al. *Transforming Public Education: A Green New Deal For K-12 Public Schools*; Climate and Community Project: Philadelphia, PA, USA, 2021.
118. Brouillette, M.J. *The Case for Choice in Schooling: Restoring Parental Control of Education, A Comprehensive Guide for Advancing Parents' Rights and Responsibilities to Direct the Education of Their Children*; Mackinac Center for Public Policy: Midland, MI, USA, 2001.
119. Filho, W.L.; Vidal, D.G.; Dinis, M.A.P.; Lambrechts, W.; Vasconcelos, C.R.; Molthan-Hill, P.; Abubakar, I.R.; Dunk, R.M.; Salvia, A.L.; Sharifi, A. Low Carbon Futures: Assessing the Status of Decarbonisation Efforts at Universities within a 2050 Perspective. *Energy Sustain Soc.* **2023**, *13*, 5. [CrossRef]
120. Price, E.A.C.; White, R.M.; Mori, K.; Longhurst, J.; Baughan, P.; Hayles, C.S.; Gough, G.; Preist, C. Supporting the Role of Universities in Leading Individual and Societal Transformation through Education for Sustainable Development. *Discov. Sustain.* **2021**, *2*, 49. [CrossRef]
121. Singer-Brodowski, M.; Förster, R.; Eschenbacher, S.; Biberhofer, P.; Getzin, S. Facing Crises of Unsustainability: Creating and Holding Safe Enough Spaces for Transformative Learning in Higher Education for Sustainable Development. *Front. Educ.* **2022**, *7*, 787490. [CrossRef]
122. Engel, H.; Hamilton, A.; Lee, L.; Woetzel, J. Target Net Zero: A Journey to Decarbonizing the Public Sector. Available online: https://www.mckinsey.com/industries/public-sector/our-insights/target-net-zero-a-journey-to-decarbonizing-the-public-sector#/ (accessed on 21 January 2024).
123. International Labour Organization; OECD. *Skills for Decarbonisation*; International Labour Organization: Genève, Switzerland, 2022.
124. Hanson, G. Local Labor Market Impacts of the Energy Transition: Prospects and Policies. In *Economic Policy in a More Uncertain World*; Kearney, M.S., Ganz, A., Eds.; The Aspen Institute: Washington, DC, USA, 2023.
125. Rebich-Hespanha, S.; Bales, R.C. Can Universities Catalyze Social Innovation to Support Their Own Rapid Decarbonization? Assessment of Community and Governance Readiness at the University of California. *Front. Sustain.* **2023**, *4*, 1115982. [CrossRef]
126. Astbury, J.; McCafferty, P.; McConahey, E. Decarbonizing The Campus of The Future. Available online: https://schoolconstructionnews.com/2022/07/19/decarbonizing-the-campus-of-the-future/ (accessed on 21 January 2024).
127. Goldberg, S.B. *Education in a Pandemic: The Disparate Impacts of COVID-19 on America's Students*; Office for Civil Rights: Washington, DC, USA, 2021.
128. Leal Filho, W.; Weissenberger, S.; Luetz, J.M.; Sierra, J.; Simon Rampasso, I.; Sharifi, A.; Anholon, R.; Eustachio, J.H.P.P.; Kovaleva, M. Towards a Greater Engagement of Universities in Addressing Climate Change Challenges. *Sci. Rep.* **2023**, *13*, 19030. [CrossRef]