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Mainstreaming Sustainability and Climate Change Across Higher Education: Lessons From Ten Pioneering Universities

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ABSTRACT

Higher education institutions (HEIs) play a critical role in preparing graduates to address the interconnected global crises of the 21st century. Despite explicit calls from UNESCO’s Education for Sustainable Development (ESD) framework (SDG 4 on quality education) and the United Nations Framework Convention on Climate Change’s (UNFCCC) Action for Climate Empowerment agenda (SDG 13 on climate action) to mainstream sustainability and climate change (S&CC) across all fields of study, integration within academic programs remains fragmented and often confined to isolated courses. This study argues that genuinely transformative education requires embedding S&CC as a core, transdisciplinary literacy across all study programs, essential for cultivating professionals capable of leading the socio-ecological transition across diverse sectors. To investigate how S&CC is systematically embedded in higher education curricula, the study employs a qualitative, multi-case study methodology drawing on a purposive sample of 10 pioneering universities across five continents. Data were gathered through systematic documentary analysis of institutional materials, including strategic plans, course syllabi, learning outcomes frameworks, and evaluation reports, and analyzed through iterative thematic analysis combining within-case and cross-case comparison. The findings reveal four distinct modes of climate change curriculum integration: dedicated modules, structural embedding, framework integration, and research-line integration, and document persistent barriers including disciplinary silos, limited faculty capacity, and accreditation constraints. The analysis further identifies a structural equity gap in which S&CC education remains concentrated at the postgraduate level, excluding most undergraduates from mandatory climate literacy. Drawing on these insights, a scalable three-phase framework is proposed: Foundation, Integration, and Institutionalization, to help HEI leaders, educators, and policymakers achieve mandatory, meaningful S&CC integration across all fields of study.

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1 | Introduction

We are in the age of polycrisis: the rapid convergence of climate change, accelerating biodiversity loss, and persistent social deprivation are not isolated crises but interlocking symptoms of fundamentally unsustainable systems (Fletcher et al. 2024; Lawrence et al. 2024). The effects of a warming world, from extreme weather events to resource scarcity, reverberate across every sector of society, demanding a radical rethinking of how we work, relate, and govern. The question is no longer whether we must transition to a sustainable and climate-resilient future, but how we do so, and do so justly (Alsharef and Hassan 2024; Mention et al. 2023). That question demands more than technological innovation or policy reform. It demands a transformation of mindset, skills, and values in the generation now entering higher education. This is where Higher Education Institutions (HEIs) must play their most consequential role (Kopp et al. 2025).

HEIs are the principal trainers of tomorrow's professionals, leaders, and citizens, and are therefore uniquely positioned to confront the climate crisis at scale (Khalo and Damoah 2023; Kopp et al. 2025). More than 220 million students are currently enrolled in higher education globally, a figure that continues to rise (UNESCO 2020). These are the engineers who will design coastal defenses, the economists who will reframe growth theory, the urban planners who will shape climate-adapted cities, the lawyers who will argue environmental cases, and the teachers who will educate the generation after them (Bangay and Blum 2010; Diaconu and Popescu 2016). Whether these graduates possess, or lack, a deep understanding of sustainability and climate change (S&CC) will substantially shape the trajectory of the socio-ecological transition (Reimers 2021; Viere et al. 2021).

The international community has responded to this urgency with increasingly forceful calls for action. UNESCO has long championed the cause, from its 1997 Declaration on the Responsibilities of the Present Generations Towards Future Generations to its more recent Education for Sustainable Development (ESD): Towards Achieving the SDGs (ESD for 2030) framework, which explicitly calls for sustainability integration across all levels and fields of education (UNESCO 1997, 2020). In parallel, the United Nations Framework Convention on Climate Change's (UNFCCC) Action for Climate Empowerment (ACE) agenda, formally launched at COP22, identifies education, training, and public awareness as essential tools for meeting climate targets (UNESCO 2016), building on Article 6 of the original Convention, which requires signatory states to develop climate education and training programs (UNFCCC 1992). Together, these frameworks position education not as a passive receiver of climate knowledge, but as an active driver of climate solutions. Yet despite their reach and authority, the gap between aspiration and practice in higher education remains wide.

The integration of S&CC into higher education curricula remains stubbornly fragmented. These topics are too often confined to environmental science or geography programs, treated as disciplinary specialisms instead of cross-cutting competencies that every graduate needs (Annelin and Boström 2024; Leal Filho et al. 2021). A business graduate may never encounter the

financial risks of stranded assets or the logic of the circular economy. A civil engineering graduate may enter practice with no grounding in climate-resilient design. Where sustainability appears at all, it is frequently a single elective, an optional encounter, not a foundational literacy. This is insufficient. Researchers of ESD have argued for two decades that this add-on model is not merely inadequate but structurally misconceived. Sterling (2001) distinguished between accommodative approaches, in which sustainability content is inserted into existing structures without disturbing their underlying logic, and transformative approaches that reconceive the purpose of education itself. Tilbury (2011) extended this, identifying participatory, future-oriented pedagogies as the necessary condition for genuine sustainability learning. Challenges of the scale and complexity of decarbonizing supply chains, adapting cities to sea-level rise, or delivering just transitions for fossil fuel workers cannot be addressed by graduates who have encountered sustainability only in passing (Wardat and AlAli 2025; Weiss et al. 2021).

A terminological note is necessary before proceeding. This study uses S&CC as a compound term throughout, reflecting the institutional reality that S&CC are consistently co-located in HEI governance structures, strategic plans, and curriculum frameworks, as rarely does an institution address one without the other. This does not imply they are analytically identical. As the theoretical discussion above makes clear, climate change constitutes a partially distinct curricular domain with its own scientific foundations and pedagogical demands that broader sustainability education does not always address. The compound term signals institutional co-occurrence; the analysis throughout the paper attends carefully to the distinction wherever it matters for curriculum design and governance.

This study makes three original contributions to the literature on S&CC in higher education. First, it develops an empirically grounded four-mode typology of S&CC curriculum integration: dedicated modules, structural embedding, framework integration, and research-line integration that goes beyond existing descriptive accounts to specify the conditions under which each mode is most effective and the trade-offs each entails. Second, it identifies and theorizes a structural equity gap in S&CC education, demonstrating that the postgraduate concentration of climate literacy systematically excludes the majority of graduates and reproduces existing social inequalities, a dimension largely absent from prior institutional analyses. Third, it proposes a scalable three-phase framework, Foundation, Integration, and Institutionalization, grounded in cross-continental evidence and designed to offer HEI leaders, educators, and policymakers a differentiated, actionable pathway toward mandatory curriculum transformation, moving beyond the high-level recommendations of existing UNESCO and competency framework guidance.

This study responds to existing literature gaps directly. Drawing on a qualitative multi-case study of 10 pioneering universities across five continents, it offers a systematic analysis of how HEIs are restructuring their curricula in practice, what works, what persists as a barrier, and what a scalable path forward looks like. The premise is that higher education must not merely anticipate the future, but deliberately and responsibly help to create it.

2 | Literature Review

Prior research on S&CC curriculum integration in higher education has developed along three interconnected lines: theoretical frameworks for transformative sustainability education, competency-based curriculum design tools, and empirical studies of institutional implementation and equity. This study builds on and synthesizes these three lines of inquiry, identifying the gap they collectively leave and that this study addresses directly.

The field of ESD provides the foundational theoretical context for understanding why S&CC curriculum integration remains so difficult to achieve at scale. Early and influential formulations argued that the challenge is not simply additive, that is, a matter of inserting sustainability content into existing courses, but structural: it requires reconceiving the purpose of education itself. Sterling (2001) drew a foundational distinction between accommodative approaches, in which sustainability content is inserted into existing educational structures without disturbing their underlying logic, and transformative approaches that reconceive what education is fundamentally for. This distinction has proven durable because it names the precise failure mode that most HEI sustainability initiatives fall into: adding content without changing the epistemological or pedagogical architecture that frames it. Tilbury (2011) extended this argument, identifying participatory, future-oriented, and inquiry-based pedagogies as the necessary conditions for genuine sustainability learning, not mere sustainability awareness. Together, these formulations converge on a shared critique: the add-on model that characterizes most HEI sustainability provision is not merely inadequate in degree but misconceived in kind.

The theoretical commitments of transformative ESD have been operationalized into curriculum design tools through the development of sustainability competency frameworks. Wiek et al. (2011) identified five key sustainability competencies that education should develop across all disciplines: systems thinking, anticipatory, normative, strategic, and interpersonal competencies. This framework has been widely adopted as a reference standard in curriculum reform initiatives and informs the deductive coding categories used in the thematic analysis of this study. More recently, the European GreenComp framework (Bianchi et al. 2022) has extended this logic into policy, specifying 12 competencies organized around embodying sustainability values, embracing complexity, and envisioning sustainable futures. Climate change education, however, occupies a partially distinct theoretical space within this broader sustainability education literature, a distinction this study takes seriously. As Molthan-Hill et al. (2022) have argued, climate literacy requires not only the systems-thinking competencies common to sustainability education but specific scientific understanding of climate mechanisms, policy literacy regarding international frameworks such as the Paris Agreement, and the capacity to engage with the psychological and political dimensions of climate inaction. Monroe et al. (2019) have similarly shown that effective climate education must move beyond knowledge transmission to foster identity-consistent engagement with climate risk, a pedagogical challenge that generic sustainability curricula do not always meet. This distinction informs the study's treatment of S&CC as a compound term: sustainability provides the overarching

normative framework, while climate change constitutes a distinct curricular domain with its own scientific foundations and pedagogical demands.

Two theoretical frameworks inform the analytical approach of this study. First, Institutional Theory, particularly DiMaggio and Powell (1983) concept of institutional isomorphism, provides a lens for understanding why universities adopt specific S&CC integration models. Coercive isomorphism explains adoption driven by regulatory and accreditation pressures; mimetic isomorphism explains adoption driven by imitation of peer institutions perceived as successful, particularly through international networks such as Principles for Responsible Management Education (PRME) and International Sustainable Campus Network (ISCN); and normative isomorphism explains adoption driven by professional norms diffused through faculty training and disciplinary associations. Together, these mechanisms help explain both convergence across institutions, the universal adoption of dedicated sustainability units and senior leadership mandates documented in this study, and divergence, the variation in integration modes and mitigation–adaptation orientations across governance types and regional contexts. Second, the Multi-Level Perspective on sustainability transitions (Geels 2002) frames curriculum reform as a niche innovation attempting to destabilize the dominant socio-technical regime of disciplinary, transmission-based higher education. This perspective informs why curriculum greening tends to emerge first at the postgraduate level, where institutional constraints are looser and faculty autonomy greater, before diffusing, often incompletely, into undergraduate provision. It also explains why externally funded programs at institutions such as Nairobi and UniFiji represent promising niche experiments that risk dissipating when project funding ends, absent the regime-level changes, accreditation reform, recurrent funding, and leadership mandates that institutionalization requires.

Empirical research on the incorporation of sustainable development into HEI curricula has identified a consistent set of barriers and drivers that shape the pace and depth of curriculum reform. On the barriers side, studies consistently document disciplinary silos, faculty resistance, rigid accreditation frameworks, and insufficient institutional support as the primary obstacles to mainstreaming sustainability across degree programs (Boks and Diehl 2006; Lozano and Barreiro-Gen 2019; Weiss et al. 2021). Lozano and Barreiro-Gen (2019), in a study of European HEIs, found that faculty attitudes and institutional culture were more decisive than resource availability in determining whether sustainability was integrated beyond isolated elective courses. Weiss et al. (2021) further identified that the pattern of curriculum change, whether driven top-down by institutional mandate or bottom-up through departmental initiative, significantly shapes both the breadth and durability of sustainability mainstreaming. On the drivers side, dedicated sustainability units with formal curriculum authority, visible senior leadership commitment, and engagement with international sustainability networks consistently emerge as the most powerful enablers of reform. These findings from prior literature provide the analytical baseline against which this study's cross-continental evidence is evaluated and inform the development of the three-phase framework proposed in Section 4.6.

The equity dimension of S&CC education has received growing but still insufficient attention in the literature. Mbah and Ezegwu (2024) have argued that formal climate curricula risk perpetuating epistemic exclusion by marginalizing the knowledge systems of communities most affected by climate change, particularly in African and other Global South contexts. Burke (2012) has demonstrated that access to transformative knowledge in higher education is never socially neutral, as it is always structured by prior inequalities of cultural capital, institutional access, and social positioning. Applied to S&CC education, this means that the question of who receives mandatory climate literacy, and at what level of study, is not merely a curriculum design question but an equity and justice question with significant implications for the socio-ecological transition. These perspectives directly inform the equity-focused dimensions of this study, particularly the analysis of postgraduate concentration and the mitigation–adaptation divergence between Global North and Global South institutions in the results section.

Despite this body of academic literature, several significant gaps remain. Existing empirical studies of S&CC curriculum integration tend to be single-institution or regionally bounded, limiting cross-contextual insight into how governance structures, disciplinary cultures, and regional vulnerability contexts interact to shape curriculum reform (Leal Filho et al. 2021; Weiss et al. 2021). The equity dimensions of S&CC curriculum concentration, particularly the systematic exclusion of undergraduates and the asymmetry between Global North and Global South curricular orientations, have been theorized but not empirically mapped across diverse institutional contexts. Moreover, while sustainability competency frameworks are well developed at the theoretical level, no study has systematically compared the governance structures and specific integration modes through which HEIs translate these frameworks into curriculum practice across multiple continents. This study addresses all three gaps directly through a qualitative multi-case study of 10 pioneering universities across five continents, combining governance analysis, curriculum typology, and equity-focused cross-case comparison within a single empirical study.

3 | Methods

This study employs a qualitative, multi-case study methodology to investigate how S&CC are systematically embedded into higher education curricula. The multi-case study design is well-suited to this inquiry as it enables in-depth, contextualized examination of complex institutional processes while supporting cross-case comparison across diverse geographical and organizational settings (Yin 2017). The approach is intentionally global and comparative, designed to capture a wide spectrum of economic, cultural, and governance conditions shaping curriculum reform in higher education.

3.1 | Case Selection and Sampling

Cases were selected through purposive sampling, targeting universities recognized as pioneers in S&CC curriculum integration. Purposive sampling is a well-established approach in qualitative and comparative higher education research, particularly suited

to studies that seek theoretical insight, not statistical representativeness (Tight 2012). In the context of cross-institutional comparative research, purposive selection of information-rich cases enables the kind of in-depth, contextually sensitive analysis that random sampling cannot achieve (Flyvbjerg 2006).

To be included in the sample, institutions were required to meet at least two of the following criteria: (i) a demonstrable institutional commitment to sustainability embedded in their strategic plans or curriculum frameworks; (ii) active membership or leadership roles in internationally recognized sustainability networks, such as the UN-supported PRME or the ISCN; and (iii) documented evidence of S&CC integration across multiple study programs, instead of in isolated courses. Universities operating sustainability initiatives exclusively at the level of campus operations, with no evidence of curricular integration, were excluded.

To maximize geographical and contextual diversity, the final sample of 10 universities comprises two institutions from each of the following regions: Europe, North America, Latin America, Africa, and the Asia-Pacific region. This regional distribution ensures that the findings reflect a broad range of institutional contexts, not the experience of any single higher education system. The selection of the specific 10 institutions within these regional pairs was guided by a further layer of differentiation. Within each region, institutions were chosen to represent contrasting governance models, centralized and federated, and contrasting resource profiles, where possible. For example, Stanford University and the University of British Columbia together represent both a newly restructured centralized model and a distributed mainstreaming approach within North America. At the same time, the University of Fiji and the University of Tokyo together capture a small island developing state institution navigating acute climate vulnerability alongside a large research-intensive national university. Institutions such as ETH Zürich or UC Berkeley, while well-regarded for sustainability activity, were not selected because they would have duplicated the governance profiles already represented in the European and North American pairs. The guiding principle was not to identify the objectively “best” institutions globally, a determination that would require different methods, but to assemble a sample that maximizes analytical diversity across governance type, resource endowment, regional vulnerability, and curricular approach, thereby enabling robust cross-case comparison. A summary of the sampled institutions, including region, institutional type, and primary basis for selection, is provided in Table 1.

3.2 | Data Collection

Primary data were gathered through documentary analysis conducted across all 10 case universities. Following Bowen’s (2009) framework for document analysis in qualitative research, documents were systematically located, appraised for relevance and credibility, and analyzed for content about S&CC curriculum integration. The document corpus comprised both publicly available materials, including university websites, published institutional reports, course syllabi, module descriptions, and learning outcomes frameworks, and non-public documents obtained through direct institutional requests, namely internal evaluation reports. Documents analyzed were published or

TABLE 1 | Overview of case study institutions, regional distribution, selection basis, and documents accessed.

Institution	Country	Region	Selection basis	Documents accessed
1. University of Oxford	UK	Europe	ISCN membership; institutional sustainability framework; cross-faculty curriculum integration	Syllabi, website, institutional reports
2. University of Twente	Netherlands	Europe	PRME membership; student-led sustainability platform; centralized curriculum strategy	Syllabi, website, institutional reports
3. Stanford University	USA	North America	Dedicated sustainability school; cross-disciplinary curriculum model; ISCN membership	Syllabi, website, institutional reports
4. University of British Columbia	Canada	North America	PRME membership; distributed mainstreaming model; sustainability-dedicated degree programs	Syllabi, website, institutional reports, internal evaluation reports
5. Universidade de São Paulo	Brazil	Latin America	Institutional sustainability governance, a dedicated environmental research unit, and curriculum integration evidence	Syllabi, website, published case reports
6. Tecnológico de Monterrey	Mexico	Latin America	PRME membership; Vice Presidency sustainability model; flagship S&CC engineering program	Syllabi, website, institutional reports
7. University of Cape Town	South Africa	Africa	Dedicated climate institute; postgraduate S&CC program; senate-level governance commitment	Syllabi, website, institutional reports
8. University of Nairobi	Kenya	Africa	Specialized climate adaptation institute; postgraduate S&CC program; regional leadership role	Syllabi, website, published case reports
9. University of Tokyo	Japan	Asia-Pacific	National university sustainability mandate; interdisciplinary sustainability science program; ISCN membership	Syllabi, website, institutional reports
10. University of Fiji	Fiji	Asia-Pacific	Regional climate vulnerability context, dedicated S&CC research center; postgraduate energy program	Syllabi, website, strategic plan

accessed between 2020 and 2025, capturing the most recent phase of institutional sustainability strategy development across the sample.

Documents were included if they directly addressed S&CC integration at the curricular level and excluded if they pertained solely to campus sustainability operations or research agendas without curricular relevance. This selection process ensured comparability across cases while remaining sensitive to the varying documentary practices and levels of institutional transparency across different national and regional contexts.

Across the 10 institutions, the document corpus comprised course syllabi, institutional strategic plans and sustainability reports, program descriptions and learning outcomes frameworks, and, where accessible, internal evaluation reports. The volume of documentation varied across institutions, reflecting differences in the availability of publicly accessible course-level materials and varying levels of institutional transparency across national and regional contexts. Where access to non-public documents was not granted, analysis proceeded based on publicly

available materials, and this limitation is noted in the relevant case profiles.

It is important to acknowledge that institutional documents, strategic plans, sustainability reports, and curriculum frameworks are produced partly for reputational purposes and therefore represent formally articulated positions that may diverge from enacted curriculum practice. This gap between aspirational documentation and operational reality is a recognized limitation of documentary analysis (Bowen 2009) and is addressed directly in the positionality and reflexivity section below.

3.3 | Analytical Approach

Data analysis followed an iterative process combining within-case and cross-case analysis. Each university was first examined individually to produce a detailed narrative profile describing its institutional strategy, implementation journey, and regional context. These profiles formed the basis for the subsequent cross-case analysis, in which data were examined

to identify shared trends, recurring strategies, and divergent challenges across institutions.

Thematic analysis, as described by Braun and Clarke (2006), was used to code and interpret documentary data. An initial set of codes was developed deductively, drawing on existing frameworks of sustainability competencies and curriculum reform, particularly the European GreenComp framework (Bianchi et al. 2022) and Wiek et al.'s (2011) sustainability competencies model. These deductive codes were complemented by inductive codes that emerged from the data, allowing the analysis to remain responsive to institution-specific and region-specific dynamics. Particular attention was paid throughout to distinguishing between universally applicable principles of S&CC curriculum integration and those that are context-dependent, reflecting the study's comparative ambition.

Analytical consistency across cases was ensured through several procedures. First, the same deductive coding framework, drawn from GreenComp (Bianchi et al. 2022) and Wiek et al. (2011), was applied uniformly across all 10 institutions before inductive codes were developed. Second, all case profiles were reviewed iteratively by the research team, with cross-case comparisons used to identify and resolve inconsistencies in code application. Formal inter-rater reliability procedures were not applied, reflecting the interpretive nature of the thematic analysis and the study's qualitative epistemological orientation. This limitation is acknowledged, and the iterative within-case and cross-case review process served as the primary mechanism for analytical validation.

3.4 | Positionality and Reflexivity

As with all qualitative inquiry, the analytical process was shaped by the researchers' own conceptual commitments and disciplinary positioning. The study approaches S&CC curriculum integration from the perspective that sustainability is not a peripheral add-on but a core dimension of contemporary higher education, a stance that informed both case selection and analytical framing. This positionality is acknowledged as a productive orientation, not a source of bias, as it enables focused and theoretically grounded inquiry.

More specifically, this orientation shaped the study in two ways that warrant transparency. First, the selection of "pioneering" institutions necessarily reflects a normative judgment about what progressive S&CC integration looks like, a judgment informed primarily by established international frameworks (UNESCO ESD, GreenComp, PRME) and the peer-reviewed literature on sustainability competencies. Institutions whose approaches depart from these frameworks in ways not captured by the selection criteria may have been systematically excluded. Second, documentary analysis of institutional materials carries an inherent limitation: universities produce strategic plans, sustainability reports, and curriculum frameworks partly for reputational purposes. The documents analyzed represent formally articulated institutional positions, which may differ from the lived experience of students and faculty navigating S&CC curricula in practice. Throughout the analysis, efforts were made to read institutional documents critically, distinguishing between aspirational language and evidence of operational implementation, and to note where claims appeared unsupported by the

documentary record. Where discrepancies between stated ambition and documented practice were apparent, these are flagged in the relevant case profiles. These limitations point toward productive directions for future research, including interview-based and student-facing methodologies that would access the dimensions of curriculum experience that documentary analysis cannot reach.

4 | Results and Discussion

To build a coherent picture of how HEIs integrate S&CC into their curricula, the analysis begins by comparing the institutional and curricular features of the sampled universities. Findings are organized around themes derived through iterative thematic analysis (Braun and Clarke 2006), combining deductive codes drawn from established sustainability competency frameworks with inductive codes emerging from the documentary data. Ten university case studies across five continents reveal that, while HEIs employ several convergent strategies for embedding S&CC, they differ markedly in how these strategies are operationalized within local governance structures, disciplinary cultures, and regional vulnerability contexts. Sustainability generally serves as the overarching normative framework, whereas climate change functions as a distinct curricular domain, rooted in physical science, shaped by its own global policy instruments, and requiring pedagogical approaches not always addressed by broader sustainability education. The extent to which institutions treat climate change as a co-equal curricular theme, instead of subsuming it under wider environmental programming, varies considerably. Two factors consistently account for this variation: disciplinary traditions and regional vulnerability profiles.

Yet, not all pioneering institutions have followed similar pathways. Institutional commitment to sustainability, as signaled through network membership and strategic declarations, does not, by itself, predict the governance structures through which that commitment is translated into the curriculum. A university may hold PRME membership and publish ambitious sustainability targets while maintaining a federated governance model that fragments curriculum reform across autonomous departments. Table 2 summarizes the governance architectures, dedicated S&CC units, flagship programs, and operational targets across the sample, and reveals that the distance between institutional aspiration and curricular reality varies considerably and is shaped above all by how governance authority is structured.

Following the governance and strategic orientations outlined in Table 2, Table 3 shifts the focus to curriculum-level design features. It compares how the 10 universities structure learning outcomes, content sequencing, and pedagogical approaches for S&CC, highlighting the degree to which climate change is treated as an independent curricular component or embedded within broader sustainability provision.

4.1 | Governance Architectures and Curriculum Integration

Governance architectures significantly shape both the pace and coherence of S&CC curriculum integration across the sample

TABLE 2 | Governance structures and strategic frameworks for sustainability across 10 universities.

Institution/ country	Governance model	Key S&CC unit	Flagship program	Stated operational target	References
University of Oxford (UK)	Federated (college autonomy)	ECI; Smith School	MSc Environmental Change and Management	Net-zero carbon and biodiversity net gain by 2035	(University of Oxford 2021)
University of Twente (Netherlands)	Centralized with a student-led platform	CSTM; Green Hub Twente	MSc Sustainable Energy Technology	Fully sustainable organization by 2030	(University of Twente, n.d.)
Stanford University (USA)	Centralized (new school model)	Doerr School of Sustainability	MS/MA Sustainability Science and Practice	Net-zero by 2050; 100% renewable electricity since 2022	(Stanford University, n.d.-c)
University of British Columbia (Canada)	Quasi-municipal; distributed mainstreaming	Sustainability Hub; IRES	Bachelor of Sustainability; MLWS (paused 2026/27)	85% reduction in operational emissions by 2030 and net-zero operational emissions by 2035	(University of British Columbia 2021)
Universidade de São Paulo (Brazil)	Decentralized (unit-based autonomy)	SGA	PROCAM (IEE)	Environmental policy with stated goals	(Universidade de São Paulo, n.d.-b)
Tecnológico de Monterrey (Mexico)	Centralized (Vice Presidency model)	Ruta Azul; Inst. for Future of Education	BS Sustainable Development Engineering; MER	Carbon neutral by 2040	(Tecnológico de Monterrey 2022)
University of Cape Town (South Africa)	Senate-governed with a dedicated institute	ACDI	MPhil Climate Change and Sustainable Development	Net-zero Scope 1 and 2 by 2050	(University of Cape Town, n.d.)
University of Nairobi (Kenya)	Public university with specialized institutes	ICCA; WMI	Master of Climate Change and Adaptation	Institutional environmental management goals under development	(University of Nairobi, n.d.-b)
University of Tokyo (Japan)	National university with interdisciplinary institutes	IFI; GPSS-GLI	MSc/PhD Sustainability Science	Net-zero by 2050	(University of Tokyo 2025)
University of Fiji (Fiji)	Private with the research center	CCCEESD	Master in Renewable Energy Management	Strategic Plan 2022–2026 with campus-level goals	(University of Fiji 2022)

institutions. Centralized strategic mandates are associated with more uniform, institution-wide reform, whereas federated and decentralized structures tend to slow and fragment implementation. Stanford's creation of the Doerr School of Sustainability in 2022 (Stanford University, n.d.-a), Tecnológico de Monterrey's *Ruta Azul* sustainability and climate plan (Tecnológico de Monterrey 2022), and the University of Twente's Shaping2030 strategy (University of Twente 2020) illustrate how centralized governance can support rapid and coherent institutional integration of S&CC.

By contrast, Oxford's federated collegiate model (University of Oxford 2021) results in undergraduate sustainability content being largely elective, with uneven reform across departments. A similar pattern is evident at USP, where unit-based governance across autonomous institutes and seven campuses fragments curriculum development (Universidade de São Paulo, n.d.-b). These findings align with Leal Filho et al. (2025), who report that clear institutional mandates and dedicated sustainability units correlate with more coherent SDG implementation, and with Robinson et al. (2023), who argue that effective sustainability

governance requires bridging the cultural divides between academic and operational domains. These patterns are consistent with DiMaggio and Powell's (1983) concept of institutional isomorphism: coercive pressures from accreditation bodies and government mandates drive reform in centralized systems, while mimetic pressures through PRME and ISCN network membership explain convergence in strategic commitments across otherwise diverse institutional contexts.

Climate-specific governance mechanisms further strengthen curriculum outcomes, not consistently observed in institutions relying on general sustainability structures alone. Institutions that explicitly embed climate change within their governance architecture, such as University of Cape Town's ACIDI (established in 2011 with dedicated climate-centric research themes) (University of Cape Town, n.d.), UTokyo's GX Promotion Subcommittee with specialized task forces (The University of Tokyo, n.d.-b), and Tecnológico de Monterrey's *Ruta Azul* framework with distinct mitigation and adaptation pillars (Tecnológico de Monterrey 2022) display more explicit and measurable climate-related curricular outputs than those addressing climate only within

TABLE 3 | Curriculum-level design features: Program level, pedagogical approach, and content orientation.

Institution	Mitigation–adaptation orientation	Program concentration	Primary pedagogical approach	References
University of Oxford	Mitigation-dominant	Postgraduate (MSc)	Interdisciplinary, research-led	(Smith School of Enterprise and the Environment (The University of Oxford), n.d.)
University of Twente	Mitigation-dominant (adaptation in MEEM Water Management)	Postgraduate (MSc)	Socio-technical systems	(University of Twente, n.d.)
Stanford University	Mitigation-dominant	Coterminal MA/MS; graduate certificates	Applied practicum; systems thinking	(Stanford University, n.d.-b)
University of British Columbia	Mixed (mitigation + adaptation + Indigenous knowledge)	Mixed (Bachelor of Sustainability (Bsust); The Master of Land and Water Systems (MLWS) paused)	Distributed mainstreaming; living lab	(University of British Columbia, n.d.-a)
Universidade de São Paulo	Mixed (low-carbon planning + climate justice)	Predominantly postgraduate	Unit-based specialization	(Universidade de São Paulo, n.d.-a)
Tecnológico de Monterrey	Mitigation-dominant (corporate sustainability emphasis)	Undergraduate and postgraduate	Challenge-Based Learning	(Membrillo-Hernández et al. 2019)
University of Cape Town	Adaptation-dominant (climate justice central)	Postgraduate (MPhil, MSc, PhD)	Transdisciplinary, justice-oriented	(University of Cape Town, n.d.)
University of Nairobi	Adaptation-dominant (community-based adaptation)	Postgraduate (MCCA, MSc, PhD)	Adaptation-centered, community-engaged	(University of Nairobi, n.d.-a)
University of Tokyo	Mitigation-dominant (GX framework)	Postgraduate (GPSS-GLI)	Global commons; resilience framing	(The University of Tokyo, n.d.-a)
University of Fiji	Adaptation-dominant (Pacific Island resilience)	Postgraduate (REM)	Applied research; community-participatory	(The University of Fiji, n.d.)

broad sustainability mandates. These patterns suggest that universities benefit from establishing dedicated climate governance units with explicit curricular oversight, positioned alongside, not nested within, broader sustainability structures.

4.2 | Structural Concentration of S&CC at the Postgraduate Level

Across all 10 institutions, S&CC curriculum provision remains predominantly concentrated at the postgraduate level. As shown in Table 3, the flagship initiatives identified are primarily master's and doctoral programs, reflecting a wider pattern observed in the literature: sustainability and climate-related competencies continue to be institutionalized first, and most systematically, at the graduate level (Whitmer et al. [2010](#)). This persistence is noteworthy in light of earlier concerns that universities were failing to achieve meaningful SDG integration in undergraduate teaching (Leal Filho et al. [2019](#)).

Undergraduate mainstreaming, by contrast, is uneven and largely elective. UBC presents one of the most comprehensive models, combining curated sustainability pathways, the Climate Teaching Connector, and a campus-as-a living-lab model through SEEDS. Yet, undergraduate exposure still depends heavily on program-level decisions, not universal requirements

(University of British Columbia, [n.d.-b](#)). Tec de Monterrey's Tec21 model mainstreams Challenge-Based Learning across undergraduate programs, including Sustainable Development Engineering (Membrillo-Hernández et al. [2019](#)), but the depth of engagement similarly varies by disciplinary area and staff capacity.

This structural concentration at the postgraduate level carries significant equity implications that extend across multiple dimensions. Most immediately, students who do not proceed to graduate study remain largely excluded from systematic and compulsory S&CC education, despite the cross-sectoral relevance of these competencies to virtually every professional field. Globally, the share of higher education graduates who go on to postgraduate study remains a minority: OECD data indicate that across member countries, only around 15%–20% of first-degree graduates enroll in master-level programs, and doctoral participation is far smaller still (OECD [2023](#)). Confining S&CC literacy to specialist master's and doctoral programs, therefore, means that the overwhelming majority of higher education graduates, those who will enter the workforce as engineers, nurses, teachers, planners, and business professionals, do so without ever encountering mandatory climate education.

The equity dimension is further compounded by the demographics of postgraduate participation. Access to postgraduate study

remains unevenly distributed across income levels, geographies, and social groups. Drawing on Bourdieu's (1986) concept of cultural capital, postgraduate study disproportionately reproduces existing privilege: students who already possess the academic credentials, financial resources, and institutional networks required for graduate entry are also the most likely to encounter rigorous S&CC education. Those least likely to receive it, students from lower-income backgrounds, first-generation attendees, and those in vocationally oriented programs, are precisely the graduates who will enter sectors most directly implicated in the sustainability transition, including construction, agriculture, public health, and social services. This is not a peripheral concern; it is a structural contradiction at the heart of higher education's claim to serve the public good in the Anthropocene. As Burke (2012) has argued, access to transformative knowledge in higher education is never socially neutral; it is always already structured by prior inequalities. The postgraduate concentration of S&CC education is, in this light, not merely a curricular design problem but an expression of whose futures higher education is actually preparing students for. From a sustainability transitions perspective (Geels 2002), postgraduate programs function as protected niches where curriculum innovation can develop sheltered from the dominant regime of disciplinary undergraduate education, explaining both their relative success and their limited diffusion into mainstream provision.

These access disparities connect to broader structural inequalities that operate across multiple dimensions simultaneously. At the regional level, the mitigation–adaptation divergence documented in Section 4.3 reveals that students in climate-vulnerable Global South institutions are more likely to receive adaptation-oriented education, while their counterparts in well-resourced Global North institutions access mitigation-focused curricula with stronger research infrastructure and international funding. Indigenous and local knowledge systems remain marginal in most institutions examined, with only UBC and the University of Nairobi demonstrating structural, not token, integration of non-Western epistemologies into S&CC curricula. Together, these dimensions, access by level of study, access by geography, and access by knowledge tradition, constitute an interlocking equity challenge that higher education governance has not yet adequately confronted.

4.3 | Climate Change Integration Typology

Before presenting the four modes, it is worth situating this typology within the existing literature on sustainability curriculum classification. Prior frameworks have typically categorized sustainability integration along a single dimension, most commonly the degree of mainstreaming, ranging from isolated elective courses to fully embedded cross-disciplinary provision (Lozano and Barreiro-Gen 2019; Weiss et al. 2021). While useful, these classifications describe the extent of integration without specifying the structural mechanism through which integration occurs. The typology developed here advances beyond this by identifying four distinct structural modes that differ not in degree but in kind, each reflecting a fundamentally different institutional theory about how climate competence is best developed. This distinction matters analytically because it explains why institutions with similar levels of stated commitment to S&CC

produce substantially different curricular outcomes, and practically because it provides curriculum designers and institutional leaders with a differentiated menu of approaches, not a single mainstreaming continuum to navigate. Four distinct modes of climate change integration emerge from the cross-case analysis. These modes cut across broader curriculum design categories, and several institutions combine more than one.

First, dedicated climate modules treat climate science as a foundational element that requires explicit, sequenced instruction. Oxford's Smith School MSc in Sustainability, Enterprise and the Environment exemplifies this approach. Module 1, Climate Change and Net-Zero, delivers physical climate science through six structured sessions spanning atmospheric physics, ocean science, and the carbon cycle, alongside economics and policy. Climate-specific content extends across five further core modules, addressing specialized topics such as climate litigation, carbon sequestration, and climate finance (Smith School of Enterprise and the Environment (The University of Oxford), n.d.). UCT's ACIDI employs a dedicated core module on the climate system, anthropogenic forcing, and African climate variability (University of Cape Town, n.d.). Nairobi's MCCA is entirely climate-dedicated, with all course units structured around climate risk management, food security, and adaptation (University of Nairobi, n.d.-b).

Second, structural embedding characterizes programs in which the entire curriculum is oriented toward climate-related challenges without isolating climate content in named modules. Twente's MSc in Sustainable Energy Technology exemplifies this mode: the entire Year 1 curriculum is organized around the energy transition as a response to climate change, with courses spanning energy sources, technology, sustainability, and socio-economics of climate-driven transitions (University of Twente, n.d.). All graduates, therefore, encounter climate content regardless of their elective choices, though the approach trades the depth of dedicated modules for breadth.

Third, framework integration embeds climate change within broader systems-thinking or capital-assets frameworks rather than treating it as a discrete subject. Stanford's Sustainability Science and Practice program embeds climate-related content within a broader sustainability curriculum (Stanford University, n.d.-c), while the Doerr School also offers a dedicated Certificate in Climate Change for students seeking greater specialization (Stanford University, n.d.-b). UBC's distributed model integrates climate change through curated course collections and Climate Teaching Connectors rather than a single program architecture (University of British Columbia, n.d.-a). Tec de Monterrey's CBL model integrates climate change through industry partnerships, with Ruta Azul ensuring climate issues are prioritized across academic courses (Tecnológico de Monterrey 2022).

Fourth, research-line integration characterizes programs in which climate change enters the curriculum primarily through faculty research specializations and thesis supervision. The University of São Paulo Program: Programa de Pós-Graduação em Ciência Ambiental (Postgraduate Program in Environmental Science) (PROCAM) addresses climate change within its third research line on socio-technical analysis, supported by Intergovernmental Panel on Climate Change (IPCC)-contributing faculty

affiliated with the Interdisciplinary Climate Investigation Center (Universidade de São Paulo, [n.d.-a](#)). UTokyo's GPSS-GLI operates similarly, with IFI faculty including IPCC lead authors delivering climate content through research supervision and field exercises in climate-vulnerable locations (The University of Tokyo, [n.d.-a](#)). UniFiji's Centre for Climate Change, Energy, Environment and Sustainable Development (CCCEESD) integrates climate change through applied research projects, including the U.S. Agency for International Development (USAID) Pacific-American Climate Fund (PACAM) coral reef mapping program and the European Policy Innovation Council (EPIC) renewable energy curriculum (The University of Fiji, [n.d.](#)).

Table 4 maps each institution against its primary and secondary integration mode, alongside its mitigation–adaptation orientation, providing a comparative overview of the typology across the full sample. Primary mode denotes the dominant structural approach; secondary mode denotes a supplementary approach where present. Mitigation/adaptation orientation is derived from flagship program content and institutional strategic documentation.

Institutions with dedicated climate modules or fully climate-focused programs produce graduates with deeper climate science literacy; structural embedding and framework integration achieve broader exposure but at variable depth. These trade-offs are not incidental; they reflect fundamentally different institutional theories about what climate competence means. Dedicated module approaches implicitly argue that climate change is a distinct body of knowledge requiring sequential, expert-led instruction. Framework integration approaches implicitly argue that climate literacy is better developed through repeated, contextualized encounters across disciplines. Neither is wrong, but the choice carries consequences for depth, reach, and equity of student exposure. Institutions should therefore approach mode selection as a deliberate strategic decision, not a default inherited from existing curriculum architecture, and should aim to combine at least two modes to achieve both depth and breadth of climate competence, as Molthan-Hill et al. (2022) argued is achievable across all university disciplines through strategically designed interventions.

The conditions under which each mode is most appropriate can be specified, at least provisionally, from the cross-case evidence. Dedicated modules are most appropriate where a critical mass of climate-specialist faculty exists and where program structures permit sequenced delivery, making them a natural fit for postgraduate provision but harder to deploy at scale in undergraduate programs with fragmented timetabling. Structural embedding is most achievable where governance is centralized and program-level reform can be mandated from above, as at Tec de Monterrey and Twente; it is the mode most capable of achieving universal undergraduate exposure, but it requires the deepest institutional commitment and is most vulnerable to dilution when content sprawl occurs across too many courses. Framework integration is the most accessible entry point for resource-constrained or federated institutions, as it requires no new program architecture, but it carries the highest risk of climate content remaining shallow or inconsistent across the curriculum without dedicated oversight. Research-line integration is the most organic mode for research-intensive universities, emerging naturally from faculty expertise, but it is the least equitable: student exposure depends entirely on supervisory assignment, and undergraduates are structurally excluded. A matrix summarizing these conditions is provided in Table 4, and the three-phase framework in Section 4.6 proposes a sequencing logic for combining modes across institutional development stages.

A second dimension of variation concerns the orientation of climate-related curriculum content toward mitigation or adaptation. Institutions in the Global North predominantly frame their climate curricula around mitigation, decarbonization, and energy transition (Oxford, Twente, Stanford, UTokyo), whereas institutions in the Global South tend to foreground adaptation, resilience, and livelihood security (Nairobi, UCT, UniFiji). However, this divergence is not a strict binary. Tec de Monterrey, despite Mexico's high climate vulnerability, centers its curriculum on mitigation and corporate sustainability. USP integrates both low-carbon planning and climate justice. UBC, although a Global North institution, illustrates how local context can diversify curricular orientations, combining Indigenous knowledge with conventional mitigation and adaptation approaches.

TABLE 4 | Climate change integration modes across 10 case institutions.

Institution	Primary integration mode	Secondary integration mode	Mitigation/adaptation orientation
University of Oxford	Dedicated modules	Research-line integration	Mitigation-dominant
University of Twente	Structural embedding	Framework integration	Mitigation-dominant
Stanford University	Framework integration	Dedicated modules	Mitigation-dominant
University of British Columbia	Framework integration	Structural embedding	Mixed
Universidade de São Paulo	Research-line integration	Framework integration	Mixed
Tecnológico de Monterrey	Framework integration	Structural embedding	Mitigation-dominant
University of Cape Town	Dedicated modules	Research-line integration	Adaptation-dominant
University of Nairobi	Dedicated modules	—	Adaptation-dominant
University of Tokyo	Research-line integration	Framework integration	Mitigation-dominant
University of Fiji	Research-line integration	—	Adaptation-dominant

Note: Primary mode denotes the dominant structural approach derived from flagship program analysis; secondary mode denotes a supplementary approach, as documented. See below for a full elaboration of each mode.

These cases indicate that institutional identity, mission, and disciplinary orientation shape curriculum content as much as geographic location.

This pattern carries theoretical significance that extends beyond curriculum design. The predominance of mitigation-oriented curricula in well-resourced Northern institutions, and adaptation-oriented curricula in more climate-vulnerable Southern ones, reflects a deeper asymmetry in whose climate futures are being centered in higher education. Mitigation curricula, with their emphasis on decarbonization, energy transition, and technological innovation, implicitly position the Global North as the primary agent of climate response. Adaptation curricula, by contrast, address the lived realities of communities already bearing disproportionate climate impacts with fewer resources to respond. This divergence is not merely a pedagogical choice; it is an expression of the unequal global distribution of climate risk, responsibility, and educational investment. As Mbah and Ezegwu (2024) argue, formal climate curricula risk perpetuating epistemic exclusion when they fail to integrate the knowledge systems and vulnerability contexts of those most affected by climate change. The risk, in other words, is that higher education reproduces rather than challenges the inequities embedded in the global climate system. Leal Filho et al. (2021) confirm that while mitigation and adaptation constitute the two core pillars of climate change education, significant resource and capacity asymmetries persist across regions, asymmetries that this study's cross-continental sample makes empirically visible. Addressing this imbalance requires not only diversifying curricular content but also reconsidering which institutions, communities, and knowledge traditions are positioned as authoritative sources in climate education globally.

A further explanatory factor, underweighted in the literature, is the role of international research funding flows in shaping the mitigation–adaptation orientation of curricula. Mitigation-related research, spanning decarbonization technologies, energy transition economics, and carbon sequestration, attracts substantially larger volumes of competitive international funding than adaptation research, which tends to be place-specific, applied, and less amenable to the generalizable outputs that major funding bodies reward. This asymmetry is well-documented: a 2021 analysis of climate finance flows found that adaptation received <10% of tracked climate finance globally, with mitigation-related investments accounting for the overwhelming majority (UNEP 2021). The curricular implications are direct: faculty research specializations, which significantly shape what is taught, are partly a function of where funding flows. Institutions in the Global North that host large climate research centers, Stanford's Doerr School, Oxford's Smith School, and Twente's SET program, have built their curricular infrastructure on the back of mitigation-oriented research portfolios, and their curricula reflect this. Conversely, the adaptation orientation at Nairobi and UniFiji is reinforced by the development-oriented funding streams, DAAD, USAID, and EU development instruments, that support their S&CC programs. The mitigation–adaptation divide in higher education curricula is, in part, a curriculum-level expression of the broader asymmetries in who funds climate knowledge production globally. Addressing it requires not only diversifying curricular content but also diversifying research funding instruments to support

the place-specific, community-engaged adaptation research that Southern institutions are best positioned to produce.

4.4 | Enablers, Barriers, and Scalability Implications

Some enablers documented across the 10 cases are scalable to any institutional setting; others depend on specific resource endowments or geographic circumstances. Transdisciplinary curriculum design is the most transferable structural enabler identified across the sample. Twente integrates socio-technical perspectives, UCT's ACIDI bridges natural and social sciences, Tec de Monterrey's CBL crosses engineering and social innovation, and Stanford grounds its curriculum in systems thinking. These four quite different implementations suggest that transdisciplinary design is achievable across a wide range of disciplinary and institutional configurations. This finding aligns with Brundiers et al.'s (2021) competency framework, which identifies systems thinking, anticipatory thinking, and normative competence as key sustainability competencies that transdisciplinary pedagogy is particularly suited to develop.

Staff development and faculty capacity-building are the scalable enablers most conspicuously missing across the sample. UBC's Climate Teaching Connectors, which deploy graduate students and postdoctoral fellows as guest lecturers across departments lacking climate expertise, are the only systematic mechanism documented, and even it relies on temporary personnel rather than permanent infrastructure (University of British Columbia, n.d.-a). This pattern suggests that most institutions may be attempting curriculum reform without adequately investing in the human capacity to deliver it. Compared with establishing new schools or research centers, staff development is a low-cost intervention, which makes its near-absence from institutional strategies all the more striking. Dedicated institutional units with curriculum authority represent a third scalable enabler, achievable at any institution. However, their impact depends on whether they hold formal program-hosting authority (as ACIDI and ICCA do) or merely advisory status (as Green Hub Twente does) (University of Twente 2020).

Context-bound enablers, such as large-scale philanthropic investment exemplified by the USD 1.69 billion in combined gifts associated with the establishment of Stanford's Doerr School (Stanford University 2022), and proximity to policy actors, such as Nairobi's relationship with UNEP (University of Nairobi, n.d.-a), help explain specific institutional successes but may not constitute directly transferable prescriptions. Tec de Monterrey's mitigation-dominant curriculum orientation, despite Mexico's climate vulnerability, illustrates how context-bound enablers shape not only the pace but the orientation of reform: the institution's private governance structure, business-school identity, and corporate partner ecosystem position entrepreneurial innovation and corporate sustainability as the primary curricular response to climate challenges. This scalable/context-bound distinction corresponds directly to the universal and context-dependent integration principles synthesized in Table 4, reinforcing the finding that coherent S&CC integration appears to require both transferable design principles and deliberate contextual adaptation.

Persistent barriers constrain scalable implementation across contexts. Rigid degree structures and accreditation constraints represent a structural barrier that limits reform even at well-resourced institutions. National quality assurance frameworks, professional accreditation bodies, and fixed credit architectures make it difficult to introduce transdisciplinary sustainability modules into established degree programs, explaining why undergraduate mainstreaming stalls even where leadership is supportive. In many cases, the primary constraint appears to be external, including accreditation bodies and ministry regulations, rather than internal. Faculty expertise gaps constitute a second persistent barrier, directly paired with the staff development enabler: the barrier is well documented, but the solution remains systematically under-deployed across the sample. External funding dependency poses a scalability risk: programs built on project funding, such as DAAD/AFAS at Nairobi and EU-EPIC at UniFiji, demonstrate proof of concept but are unlikely to scale without transition to recurrent institutional funding, reflecting a well-documented pattern in which international development cooperation produces short-term capacity gains that dissipate when project cycles end (Janus et al. 2015). The vulnerability of externally funded programs at Nairobi and UniFiji reflects a well-documented dynamic in sustainability transitions: niche experiments supported by project funding rarely achieve regime-level change without complementary shifts in accreditation frameworks, recurrent budgets, and leadership mandates. Finally, disciplinary fragmentation, reflected in established departments' resistance to ceding curriculum space to transdisciplinary content, operates across all institutions regardless of governance type and should be recognized as a structural barrier rather than treated as an implicit background condition.

These findings point to the need for differentiated strategies. Resource-constrained institutions may benefit from prioritizing staff development and transdisciplinary redesign of existing courses, while well-resourced institutions could invest in structural reforms that grant sustainability units formal curriculum authority. Across all institutional types, proactive engagement with accreditation bodies may help create space for S&CC content within degree frameworks.

4.5 | Regional Adaptation and Integrative Synthesis

The 10 cases demonstrate that global sustainability frameworks, such as the SDGs, the Paris Agreement, and the Talloires Declaration (TD), are operationalized differently across contexts, reflecting not merely geographic differences but distinct institutional understandings of climate change as a policy problem. This variation may be understood not as a limitation but as a necessary condition for contextually appropriate implementation. As Leal Filho et al. (2023) argued, the SDGs may not be achieved by 2030 without more differentiated and contextually sensitive implementation strategies, an observation that applies with particular emphasis to higher education curricula. Table 5 presents a structured summary of universal and context-dependent integration principles derived from the cross-case evidence.

Two primary drivers appear consistently across the sample, regardless of institutional or regional context. First, dedicated

sustainability units are a prerequisite. Without an organizational anchor, curriculum reform rarely survives routine administrative turnover. Second, active support from senior leadership is essential. Where vice-chancellors or rectors do not visibly champion S&CC integration, initiatives tend to stall or regress. These structural characteristics function as essential prerequisites for the more advanced educational developments that follow (Brundiers et al. 2021).

Context-dependent principles reflect the diversity of conditions across the sample. Regional climate vulnerability might shape the mitigation–adaptation orientation, though institutional identity complicates any simple North/South mapping. The pace of undergraduate mainstreaming tracks governance centralization. Institutions such as Tec de Monterrey and Stanford have deployed institution-wide reforms at speeds that federated institutions cannot replicate without structural change. This finding is consistent with one of the patterns identified by Weiss et al. (2021), who found that top-down and centralized governance tend to promote the institutional breadth of sustainability mainstreaming. However, the same study also identified bottom-up and departmental pathways through which curriculum change can take root, suggesting that centralization is one pathway among several rather than a universal prerequisite. Indigenous and local knowledge integration is more institutionally visible in some cases than others, including UBC through its relationship with Musqueam (University of British Columbia, 2024) and the University of Nairobi through the Wangari Maathai Institute legacy (University of Nairobi, n.d.-c). However, such integration remains marginal at most other institutions, a disparity that aligns with Mbah and Ezegwu's (2024) identification of ongoing epistemic exclusion in formal climate and environmental curricula.

One productive tension warrants explicit attention. UTokyo possesses a centralized governance GX Subcommittee, the longest sustainability history in the sample cases since 1994 (University of Tokyo, n.d.), and IPCC lead authors on faculty, yet the evidence does not position it as a leader in undergraduate mainstreaming. The most likely explanation is that the GPSS-GLI model concentrates capacity in a highly selective English-language graduate program rather than distributing sustainability content across the broader undergraduate curriculum. This suggests that governance centralization and institutional longevity are necessary but not sufficient for mainstreaming; deliberate undergraduate-facing design is a separate requirement.

Resource equity remains a structural constraint that the field has not adequately addressed. The most resource-rich institutions benefit from philanthropic endowments, competitive research grants, and industry partnerships that are structurally unavailable to institutions such as UniFiji and the University of Nairobi. International sustainability education networks and funding bodies should consider differentiated support mechanisms, open curriculum resources, South–South capacity-sharing partnerships, dedicated SIDS climate education funding, and accessible accreditation pathways to address the pedagogical asymmetries documented in this study. The structural implications are clear. Dedicated units, leadership mandates, staff development, accreditation engagement, and deliberate undergraduate-facing design are the operational priorities. However, the findings also carry an ethical dimension. The resource constraints documented at

TABLE 5 | Universal and context-dependent integration principles across 10 institutions.

Integration principle	Universal or context-dependent?	Enabling mechanism	Prevalence	Supporting evidence
Dedicated institutional unit for S&CC	Universal	Organizational anchoring of curriculum coordination	All 10 institutions	ECI/Smith School (Oxford), ACIDI (UCT), ICCA (Nairobi), CCCEESD (UniFiji), Doerr School (Stanford)
Explicit senior leadership mandate for S&CC	Universal	Signaling and resource allocation authority	All 10 institutions	VC mandate (UCT, UniFiji), Rector endorsement (Tec de Monterrey), GX Subcommittee (UTokyo)
Postgraduate concentration as primary curricular vehicle	Universal	Research capacity generates pedagogical expertise	All 10 institutions	Flagship MSc/MPhil programs at every institution
External funding as program enabler	Universal (degree varies)	Financial catalysis of infrastructure and staffing	8 of 10 institutions	DAAD/AFAS (Nairobi), EU EPIC (UniFiji), philanthropy (Stanford)
Mitigation vs. adaptation orientation	Context-dependent: regional vulnerability	Climate risk profile shapes curricular framing	Clear divergence	Mitigation: Oxford, Twente, Stanford, UTokyo; Adaptation: Nairobi, UCT, UniFiji; Mixed: UBC, USP, Tec
Pace of undergraduate mainstreaming	Context-dependent: governance structure	Curriculum approval authority determines reform speed	Centralized vs. federated	Tec21 and Doerr School enable rapid mainstreaming; Oxford and USP are constrained.
Indigenous/local knowledge integration	Context-dependent: cultural context	Historical obligations and community partnerships	3 of 10 institutions	Structurally embedded at UBC and UoN; informal at UniFiji; marginal elsewhere.
SDG framing of curriculum outcomes	Context-dependent: reporting capacity	Institutional capacity for assessment frameworks	Variable	Explicit at Tec de Monterrey, UCT, UTokyo; inferred at UniFiji and UoN
Campus-as-living-lab pedagogy	Context-dependent: operational autonomy	Institutional control over physical infrastructure	3–4 institutions	UBC (quasi-municipal), Stanford (SESI), Tec de Monterrey (Distrito Tec)
Industry/policy co-production of curriculum	Context-dependent: regional economy	Corporate ecosystem and policy proximity	Variable	Strong at Tec de Monterrey, Stanford, Twente; limited at UniFiji, USP, UoN

UniFiji and Nairobi are not failures of institutional will; they are consequences of global inequalities that sustainability education ought to confront directly.

Figure 1 synthesizes the key lessons emerging from the cross-case analysis, pairing each finding with the institutional evidence on which it is based. Each lesson is paired with the institutional evidence on which it is based. Taken together, these findings suggest that effective S&CC curriculum integration depends on a combination of universal structural prerequisites and context-sensitive design choices, and that the gap between pioneering practice and sector-wide implementation remains substantial.

4.6 | A Three-Phase Framework for S&CC Curriculum Integration

The cross-case analysis points toward a practical three-phase framework for institutions seeking to achieve systematic S&CC curriculum integration: Foundation, Integration, and Institutionalization. Each phase has distinct prerequisites, actions, and success indicators. The framework does not prescribe a single model but offers a flexible, evidence-based pathway adaptable to diverse governance structures, resource endowments, and regional contexts. Figure 2 provides a schematic overview; the subsections below elaborate on each phase.



FIGURE 1 | Key lessons learned from the cross-case analysis of S&CC curriculum integration.

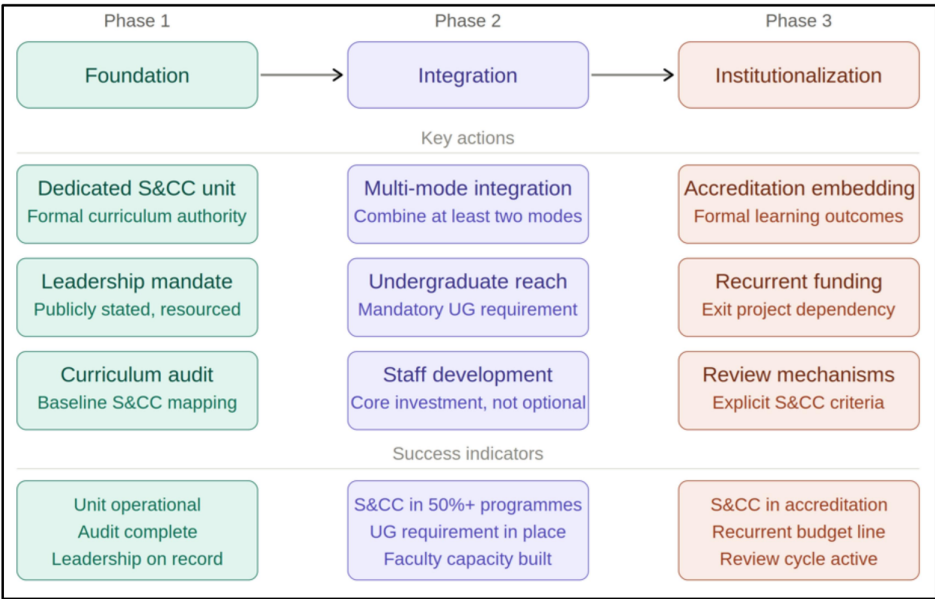


FIGURE 2 | Three-phase framework for S&CC curriculum integration.

4.6.1 | Phase 1: Foundation

The first phase establishes the structural prerequisites without which curriculum reform cannot take root. This requires three concrete actions: establishing a dedicated S&CC unit with formal curriculum authority, not merely advisory status; securing an explicit senior leadership mandate that is publicly stated and resourced; and conducting a baseline audit of existing S&CC provision across all degree programs. The cases of UCT, Tec de Monterrey, and UTokyo demonstrate that without these anchors, reform initiatives remain vulnerable to administrative turnover and competing institutional priorities. Critically, this phase requires no significant financial investment; it is

fundamentally a question of governance will. The success indicator for Phase 1 is operational: the unit exists, the audit is complete, and leadership commitment is on record in institutional documentation. In terms of resource implications, this phase requires no significant financial investment beyond staff time for the audit process and governance coordination.

4.6.2 | Phase 2: Integration

The second phase embeds S&CC content systematically across the curriculum. Institutions should select from the four-mode typology developed in Section 4.3, dedicated modules, structural

embedding, framework integration, and research-line integration, combining at least two modes to achieve both depth and breadth of climate competence. The selection of modes should be guided by disciplinary profile and governance structure: institutions with centralized governance and engineering-heavy programs may find structural embedding most efficient, while federated research universities may find research-line integration the most natural entry point. Critically, Phase 2 must extend beyond postgraduate provision to include mandatory foundational S&CC content at the undergraduate level, directly addressing the equity gap documented in Section 4.2. Staff development is the most consistently under-deployed enabler at this stage and should be treated as a core institutional investment, not an optional supplement. The success indicator for Phase 2 is distributional: S&CC content appears in at least half of all programs, a mandatory undergraduate requirement is in place, and faculty capacity has been systematically built. Resource implications at this stage include staff development funding, curriculum redesign time, and where necessary, the appointment of sustainability coordinators with cross-faculty remit. Progress should be evaluated annually through curriculum coverage mapping and faculty training records.

4.6.3 | Phase 3: Institutionalization

The third phase secures the reforms achieved in Phase 2 against the risk of regression, the most common failure mode in curriculum reform (Weiss et al. 2021). This requires three actions: embedding S&CC learning outcomes within formal accreditation frameworks, which protects reforms from internal budget pressures and leadership changes; transitioning externally funded programs to recurrent institutional budgets, which addresses the external funding dependency documented at Nairobi and UniFiji; and establishing regular curriculum review mechanisms with explicit S&CC criteria, which ensures ongoing quality assurance, not one-time compliance. UBC's distributed mainstreaming model and Stanford's Doerr School illustrate different but equally instructive pathways toward this kind of structural permanence. The success indicator for Phase 3 is systemic: S&CC appears in accreditation documentation, a recurrent budget line exists, and a review cycle is active. Resource implications center on transitioning externally funded programs to recurrent institutional budgets. Evaluation at this stage should be embedded within existing accreditation review cycles and supplemented by periodic curriculum audits with explicit S&CC criteria.

It is important to note that these phases are sequential in logic but not strictly linear in practice. Resource-constrained institutions may find it necessary or productive to begin Phase 2 staff development activities concurrently with Phase 1 governance work. Context-bound enablers, philanthropic investment, policy proximity, and regional vulnerability pressure may accelerate progress through the phases at particular institutions. What the framework insists on is a sequence of priority, not rigid chronology: governance prerequisites must be in place before curriculum redesign can achieve lasting impact, and curriculum redesign must be consolidated before institutionalization efforts will hold.

Throughout all three phases, institutional leadership is the single most decisive variable. Where vice-chancellors, rectors, and

deans visibly champion S&CC integration, allocating resources, engaging accreditation bodies, and holding faculties accountable for curriculum reform, change happens at scale and pace. Where leadership support is absent or merely rhetorical, even well-designed initiatives stall. This finding carries a direct message for higher education governance: curriculum greening cannot be delegated entirely to sustainability offices or committed individual academics. It must be owned at the highest institutional level.

5 | Conclusions

The evidence assembled across 10 pioneering universities on five continents confirms that integrating S&CC into higher education curricula is neither a peripheral aspiration nor an insurmountable institutional challenge. However, it does require deliberate, phased, and leadership-driven reform. Fragmented, elective, and postgraduate-concentrated approaches are no longer adequate responses to the scale and urgency of the sustainability transition. What the evidence demands is systemic curriculum greening: mandatory, transdisciplinary, and equity-oriented S&CC literacy embedded across all levels and fields of study.

The three-phase framework developed in Section 4.6: Foundation, Integration, and Institutionalization offers a scalable, evidence-based pathway toward this goal. Its value lies not in prescribing a single institutional model but in specifying the sequence of priorities that the cross-case evidence consistently supports: governance prerequisites before curriculum redesign, curriculum redesign before institutionalization. Institutions that conflate these phases, attempting to embed S&CC in accreditation frameworks before establishing dedicated units or launching undergraduate mainstreaming before building faculty capacity, are likely to encounter the same regression and fragmentation documented across the sample.

Several limitations of this study warrant acknowledgment. The purposive sample of pioneering institutions, while analytically productive, overrepresents successful cases of S&CC integration and is not representative of the broader higher education landscape. Institutions that have struggled with sustainability curriculum reform, whether due to resource constraints, governance fragmentation, or cultural resistance, are absent from the sample, which limits the transferability of findings to the wider sector. The frameworks and typology developed here should therefore be read as generative and aspirational, not statistically generalizable. The exclusive reliance on documentary data means that formally articulated institutional positions are captured more fully than enacted curriculum practice or the lived experiences of students and faculty. Key barriers, including faculty expertise gaps and disciplinary resistance, are inferred from documentary evidence, not explained through direct testimony, and whether students actually achieve S&CC literacy outcomes cannot be validated through this methodology alone. Finally, formal inter-rater reliability procedures were not applied in the coding process, reflecting the interpretive nature of the thematic analysis.

These limitations point toward four productive directions for future research. First, comparative studies extending the sample to non-pioneering institutions would assess the gap between best

practice and sector-wide reality. Second, longitudinal studies of curriculum implementation would capture whether the reforms documented here prove durable over time. Third, student-facing assessments of S&CC literacy outcomes would test whether formal curriculum integration translates into genuine competency development. Fourth, interview-based and multi-coder methodologies would access the dimensions of curriculum experience and analytical rigor that documentary analysis alone cannot achieve.

Higher education's claim to societal relevance in the Anthropocene ultimately depends on whether its graduates, across all disciplines, not only specialist programs, leave university equipped to understand, navigate, and lead the sustainability transition. The institutions that act on the framework proposed here first will not only serve their students better; they will define what responsible higher education looks like in the decades ahead.

Author Contributions

Walter Leal Filho: conceptualization, writing – original draft, formal analysis. **Tarek Ben Hassen:** writing – original draft, conceptualization, writing – review and editing, methodology. **Maria Alzira Pimenta Dinis:** conceptualization, writing – original draft, writing – review and editing, methodology. **Chih-Cheng Lin:** methodology, formal analysis, writing – original draft. **Wen-Hong Liu:** methodology, formal analysis, writing – original draft.

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