A System Dynamics Approach to Catalyze Environmental Sustainability in Higher Education and Research Organizations

A Research Dissertation

Presented

by

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ABSTRACT

Environmental sustainability has become a strategic imperative for higher education and research organizations (HEROs), yet many HEROs struggle to translate sustainability commitments into durable, system-wide outcomes. Existing research has largely relied on static frameworks, descriptive case studies, and performance rankings, offering limited insight into the dynamic processes through which sustainability strategies evolve, stabilize, or erode over time. This dissertation addresses this gap by examining sustainability transformation in higher education through the lenses of organizational change, strategic management, dynamic capabilities, and innovation and entrepreneurship. The dissertation develops and applies a System Dynamics (SD) modeling framework to capture the feedback mechanisms, delays, and path dependencies that shape sustainability performance in complex academic organizations. Five policy scenarios are simulated: governance and strategy integration, dynamic capability building, organizational change and cultural transformation, sustainability innovation ecosystem acceleration, and institutional context differences between U.S. and international higher education systems. Model calibration and validation draw on publicly available AASHE STARS data, enabling empirical grounding while preserving theoretical rigor. Results demonstrate that no single policy lever is sufficient to generate sustained sustainability performance. Instead, durable progress emerges from coordinated and sequenced interventions that align governance structures, organizational capabilities, cultural dynamics, and innovation ecosystems. The findings highlight complementarities and trade-offs among policy approaches and reveal how institutional context conditions the pace and stability of sustainability transitions. A case study application to the University System of Maryland illustrates how the SD model can function as a strategic learning and decision-support tool for system-level leadership. The dissertation contributes to theory by integrating dynamic capabilities and sustainability transitions within a formal dynamic framework, and to practice by offering actionable insights for university leaders and policymakers seeking to manage sustainability as a long-term organizational transformation.

Directed by: Prof. Saša Petar, Ph.D.

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CHAPTER 1

INTRODUCTION

1.1 Background and Context

Environmental sustainability has become one of the most significant strategic imperatives of the 21st century, shaping policy, organizational behavior, and societal expectations across sectors. Higher education and research organizations (HEROs), i.e., universities, colleges, and research institutes, play a unique and multi-dimensional role in advancing sustainability. They serve simultaneously as anchors of scientific knowledge, laboratories for innovation, educators of future leaders, and stewards of large and complex physical infrastructures (Cortese, 2003; Lozano et al., 2015). With over 20,000 HEROs worldwide and significant economic and environmental footprints, universities occupy a critical position in the response to climate change, resource scarcity, and the global shift toward sustainable development (Tilbury, 2011).

Over the past two decades, governments, accreditation bodies, funding agencies, and society have increased expectations that HEROs adopt comprehensive sustainability strategies that span operations, curriculum, research, community engagement, and governance (Wright, 2010). Initiatives such as the United Nations Sustainable Development Goals (UNESCO, 2017), the Association for the Advancement of Sustainability in Higher Education (AASHE) Sustainability Tracking, Assessment & Rating System (STARS), and the Times Higher Education Impact Rankings have formalized sustainability as a dimension of institutional performance and global competitiveness (Findler et al., 2019).

More recently, over the past decade, and particularly within the last five years, scholars and policymakers have emphasized the critical role of HEROs in advancing the United Nations

Sustainable Development Goals (SDGs), supporting climate adaptation, promoting environmental justice, and generating the technological and social innovations required to navigate the accelerating climate crisis (Leal Filho et al., 2023; Agyeman & Newell, 2024). As a result, environmental sustainability has moved from a peripheral concern to a core strategic priority for universities worldwide.

Despite these pressures, the integration of sustainability within HEROs remains uneven and often fragmented. Many institutions adopt sustainability rhetoric in mission statements but struggle to execute transformative institutional change due to decentralized governance, resource constraints, disciplinary silos, and competing strategic priorities (Brinkhurst et al., 2011; Leal Filho et al., 2019). This implementation gap raises fundamental questions about how HEROs can build the organizational capabilities required to transform their strategies, structures, and cultures in ways that meaningfully advance sustainability.

And while commitments have been made and advances achieved, numerous studies continue to show that HEROs experience significant challenges in institutionalizing sustainability across their organizational structures, academic programs, governance systems, and cultures. The gap between rhetorical commitments and practical implementation remains substantial, with many HEROs struggling to translate sustainability visions into actionable strategies, measurable outcomes, and enduring change (Fissi et al., 2021; Leal Filho et al., 2022). Addressing sustainability in a comprehensive and durable manner requires not only technical solutions but also deep organizational transformation: changes in how decisions are made, how departments/units collaborate, how incentives are aligned, and how leadership engages internal and external stakeholders. These challenges are compounded by the distinctive characteristics of the higher education sector, including decentralized governance, strong professional autonomy, disciplinary silos, entrenched norms and traditions, and competing academic priorities (Marshall et al., 2023; Rieg et al., 2021).

Against this backdrop, HEROs face mounting pressures from multiple sources. Governmental bodies increasingly expect universities to contribute to climate adaptation and resilience planning, while accreditation agencies, international ratings systems, and sustainability networks have created new performance metrics and accountability structures (Findler et al., 2019; Alghamdi & den Heijer, 2021). Students, faculty, community organizations, and social movements also play an important role in pushing universities to adopt stronger climate policies and sustainability commitments, often through activism, advocacy, and participatory governance structures (Agyeman & Newell, 2024). In addition, universities operate within competitive environments in which sustainability credentials can influence student recruitment, donor support, faculty hiring, and global reputation (Roy et al., 2022). These internal and external dynamics together create what institutional theorists describe as a complex field of coercive, normative, and mimetic pressures that shape sustainability trajectories in HEROs.

While sustainability pressures continue to intensify, universities are increasingly expected to leverage their assets, e.g., research expertise, innovation capacity, human capital, and community connections, to drive sustainability solutions not only within their campuses but across their regions and industries. The rise of the entrepreneurial university and the shift toward innovation ecosystem models reflect this growing expectation that HEROs play a catalytic role in generating sustainability-oriented entrepreneurship, fostering green technology development, and supporting community-based climate initiatives (Meek et al., 2023; Dote-Pardo et al., 2025; Neudert et al., 2024). The concept of the university as a "living lab" for sustainability, where campuses serve as testbeds for experimentation and interdisciplinary collaboration, has gained traction as HEROs increasingly position themselves as engines of sustainable innovation. Yet empirical research suggests that the ability of universities to fulfill these roles varies considerably depending on institutional capabilities, organizational coherence, and strategic orientation.

This variability raises important questions about why some HEROs are more effective than others in sensing sustainability opportunities and risks, mobilizing resources, implementing ambitious sustainability strategies, and generating sustainability-driven innovation. Dynamic capabilities theory (DCT), with its emphasis on sensing, seizing, and reconfiguring, represents a powerful but underutilized framework for examining these differences (Teece, 2007; Gohr et al., 2023; Shen et al., 2025). Within the past five years, researchers have begun exploring the applicability of DCT to higher education settings, particularly in the context of technological and organizational change (Guerrero, 2024; Abunaser et al., 2025). However, research explicitly linking dynamic capabilities to sustainability transformation in universities remains limited. This dissertation addresses this gap by conceptualizing sustainability transformation as a dynamic, capability-based process mediated by strategic choices and organizational change mechanisms.

Organizational change theory also provides important insights into how sustainability initiatives take root (or struggle to do so) in academic contexts. Transformative sustainability change requires more than operational adjustments; it demands cultural alignment, shared understanding, distributed leadership, and sustained engagement across diverse university actors (Marshall et al., 2023; Rieg et al., 2021). Recent studies have emphasized the importance of sensemaking, cross-unit collaboration, and adaptive governance structures in advancing sustainability transitions within HEROs. Yet, much remains unknown about how organizational change processes interact with strategic sustainability priorities and dynamic capabilities to generate sustainability-related outcomes.

The strategic management literature on sustainability further underscores the potential for universities to integrate sustainability as a core strategic differentiator. In recent years, HEROs have increasingly incorporated sustainability into institutional vision statements, strategic plans, and branding efforts (Fernandez & Nagesh, 2023). However, strategic commitment alone does not guarantee sustainability outcomes. The literature highlights the need for alignment between strategy, organizational design, resource allocation, and stakeholder engagement (Fissi et al., 2021). This dissertation responds to calls for greater empirical investigation into how HEROs translate sustainability strategies into performance outcomes through capability development and organizational change.

Finally, the entrepreneurial university and innovation ecosystem literature offers a framework for examining how sustainability intersects with institutional missions and external partnerships. Universities increasingly participate in sustainability-oriented innovation networks, community partnerships, industry collaborations, and regional resilience efforts (Neudert et al., 2024; Trevisan et al., 2024). Yet, the mechanisms through which sustainability strategies and dynamic capabilities influence innovation and entrepreneurial ecosystems remain understudied, particularly in comparative international contexts.

Taken together, these literature references highlight the complexity and importance of sustainability transformation in HEROs, as well as significant gaps in our understanding. This dissertation aims to address several of these gaps by examining the interplay of sustainability strategy, dynamic capabilities, organizational change processes, and innovation ecosystem outcomes across U.S. and international universities.

1.2 Problem Statement

Although HEROs have adopted sustainability frameworks, only a small proportion have successfully integrated sustainability into core strategic and operational functions (Shriberg, 2002; Lozano, 2011). Many sustainability initiatives remain isolated within facilities units, student groups, or individual academic departments without being embedded institution-wide (Sharp, 2002). Studies highlight structural inertia, fragmented governance, misaligned incentives, and lack of senior leadership engagement as persistent obstacles to meaningful progress (EUCEN, 2018; Ferrer-Balas et al., 2008).

Many HEROs struggle to institutionalize sustainability in ways that produce sustained, organization-wide transformation. Although universities increasingly adopt sustainability plans, climate commitments, and SDG-related initiatives, research shows that implementation often remains fragmented and inconsistent across campus units (Leal Filho et al., 2022; Fissi et al., 2021). Universities face persistent challenges in aligning sustainability goals with academic priorities, mobilizing resources, building cross-functional collaboration, and overcoming cultural resistance. As a result, HEROs vary widely in their ability to develop the capabilities needed to respond to sustainability demands, implement innovative sustainability initiatives, and achieve meaningful performance outcomes.

Furthermore, the management literature lacks a cohesive explanation of *how* HEROs develop the strategic management practices, organizational change processes, and dynamic capabilities necessary to address sustainability in a systematic, long-term manner. HEROs are complex professional bureaucracies with unique governance characteristics distinct from traditional corporate organizations (Bleiklie et al., 2015). This complexity complicates change and requires theoretical frameworks tailored to the higher education context.

Across the international landscape, the challenges and opportunities are further shaped by differences in national governance systems, public funding models, cultural norms, and levels of economic development (Altbach, 2016). The United States, for example, features a highly decentralized, market-oriented higher education system, while many European and Asian systems are more centrally regulated. These variations influence HEROs' sustainability strategies and capacity for innovation.

The problem, therefore, is that existing research does not sufficiently explain the organizational and strategic mechanisms through which HEROs mobilize sustainability initiatives, develop dynamic capabilities, and generate innovation and entrepreneurship outcomes across different national contexts. This dissertation addresses the problem of how HEROs develop and deploy organizational capabilities to support environmental sustainability, examining the relationships among sustainability strategy, dynamic capabilities, organizational change processes, and sustainability-driven innovation and entrepreneurship. The study aims to identify the core factors that explain why some HEROs achieve sustainability transformation while others fall short.

1.3 Purpose of this Research

The purpose of this dissertation is to investigate the organizational, strategic, and capability-based drivers of sustainability transformation in U.S. and international HEROs. The study examines how sustainability strategies influence the development of dynamic capabilities, how those capabilities interact with organizational change processes, and how these interactions shape sustainability innovation outcomes and institutional performance. By integrating multiple theoretical frameworks and employing a System Dynamics (SD) modeling methodology, the research aims to produce a comprehensive understanding of sustainability transformation as a multi-level, dynamic, and context-dependent process.

Specifically, the study aims to examine:

- How HEROs incorporate environmental sustainability into institutional strategy and governance.
- How dynamic capabilities—sensing, seizing, and reconfiguring—emerge and evolve within HEROs in response to sustainability pressures (Teece, 2007).
- How sustainability initiatives foster innovation, new venture creation, and entrepreneurial ecosystems within HEROs.
- How institutional context (U.S. vs. international) shapes these processes.

This research dissertation will contribute theoretical insights and practical tools for higher education leaders seeking to advance sustainability transformation.

1.4 Research Significance

This dissertation makes several important contributions. Theoretically, it bridges multiple lines of research that have traditionally been studied in isolation, e.g., dynamic capabilities, sustainability strategy, organizational change, and entrepreneurial university theory, thereby advancing a more integrated understanding of sustainability transformation in HEROs. Practically, the study provides evidence-based insights that can help university leaders strengthen their sustainability strategies, governance approaches, and capability development processes. Methodologically, it introduces validated measurement tools and employs a prospective scenario modeling design that can be replicated in future research. Finally, from a societal perspective, the dissertation strengthens understanding of how HEROs can contribute to broader sustainability transitions, climate adaptation efforts, and community resilience initiatives.

Theoretical Significance

This dissertation integrates multiple bodies of literature, e.g., strategic management, organizational change, dynamic capabilities, innovation, and higher education research, to create a unified model explaining sustainability transformation in universities. It advances:

- Dynamic capabilities theory applied to non-profit, knowledge-intensive organizations (e.g., sensing emerging environmental requirements).
- Strategic sustainability as a dimension of institutional competitiveness and differentiation.
- Entrepreneurial university theory, highlighting sustainability as a driver of innovation and partnerships.

By comparing U.S. and international HEROs, the study also contributes to global higher education research by identifying institutional configurations associated with effective sustainability strategies.

Practical Significance

HERO leaders, policy makers, and sustainability practitioners can benefit from:

- A diagnostic framework for assessing sustainability readiness and capability gaps.
- Evidence-based strategies for embedding sustainability across academic, operational, and community dimensions.

- Insights into how sustainability can catalyze new ventures, partnerships, and innovation ecosystems.
- Comparative insights from international institutions that can inform policy and governance reforms.

1.5 Research Questions

This dissertation is guided by the following primary research questions:

1. How do HEROs conceptualize and integrate environmental sustainability into their institutional strategies and governance structures?
2. What dynamic capabilities do HEROs develop to support sustainability transformation, and how do these capabilities vary across institutional contexts?
3. How do organizational change mechanisms facilitate or hinder the implementation of sustainability strategies in HEROs?
4. How do sustainability strategies and dynamic capabilities influence sustainability-driven innovation and entrepreneurship within HEROs?
5. How do sustainability transformation processes differ between U.S. and international institutions?

1.6 Case Study Focus – University System of Maryland

To enhance empirical grounding and practical relevance, the research includes a case study application focused on the University System of Maryland (USM). USM represents a large, multi-campus public university system operating within a U.S. policy and accountability environment characterized by strong sustainability mandates, competitive pressures, and leadership turnover.

The University System of Maryland (USM) in the United States has embarked on an ambitious initiative to increase its focus on sustainability issues across its education, research and operational activities. This need for change is driven by an increasing urgency to reduce the environmental footprint of the USM on natural resources such as water, energy and land, and decrease USM contributions to the global issue of climate change (USM Strategic Plan 2030).

The USM consists of a network of 15 Higher Education and Research Organizations (HERO) located throughout the state of Maryland (see Figure 1-1) with a combined $8B annual budget, 40,000 employees, and over 170,000 students. These institutions are varied in size and scope, ranging from large research universities (e.g., University of Mayland, University of Maryland Baltimore County, University of Maryland Baltimore) to undergraduate education focused institutions (Salisbury, Towson, Frostburg State, University of Baltimore), to historically black colleges/universities (University of Maryland Eastern Shore, Coppin State, Bowie State) to niche specialized institutions (University of Maryland Global Campus, University of Maryland Center for Environmental Science), to regional higher education centers (Southern Maryland, Hagerstown, Shady Grove).

Organizational change towards sustainability has increasingly gained attention in global sustainability research and policy discourse in recent years (Sancak, 2023; McGeown and Barry, 2023). Sustainability widely is recognized as one of the greatest challenges in organizational change management. In a diagnosis phase conducted over the past year, a review of published documents and other publicly available materials at USM HEROs was complemented with initial interviews of sustainability-related personnel in these institutions. A survey of sustainability efforts in other state university systems in the US (e.g., New York, California, Colorado, Virginia) and other large HERO (e.g., Harvard, Arizona State, Penn, Pitt, Princeton) was conducted based on publicly available materials. Based on these efforts, an initial set of strategies towards enhancing sustainability in the USM has been devised based on a review of principles of organizational development (OD), OD change processes, barriers to change and external/internal impacts. In the USM, although the need for developing a sustainable strategy is clear (as stated in its overarching strategic plan), a research-based process towards implementation process needs to be developed. Overall, transformation towards sustainability in HEROs is still a relatively new research area, and in the USM it needs careful implementation, particularly in terms of how it is operationalized.

The case study uses publicly available AASHE Sustainability Tracking, Assessment & Rating System (STARS) data, anchored by the flagship University of Maryland, College Park, to calibrate and validate the System Dynamics model (AASHE, 2023). USM is treated as a system-of-systems, allowing examination of how system-level governance interacts with campus-level capabilities, culture, and innovation. The case study demonstrates how the SD model can support strategic learning, scenario analysis, and policy design at the system level.

1.7 Dissertation Structure

The remainder of the dissertation is organized as follows. Chapter 2 reviews the literature on sustainability in higher education, strategic management, dynamic capabilities, organizational change, and innovation and entrepreneurship. Chapter 3 develops the theoretical framework and articulates the conceptual relationships among key constructs. Chapter 4 presents the research methodology, including the System Dynamics modeling approach, policy scenario design, and calibration/validation strategy employed. Chapter 5 reports and discusses the simulation results across five policy scenarios. Chapter 6 applies the modeling results and insights to the University System of Maryland through a detailed case study. Chapter 7 concludes the dissertation by synthesizing findings, discussing contributions and implications, acknowledging limitations, and outlining directions for future research and practice.

Figure 1-1*: Location of University System of Maryland (USM) Higher Education and Research Organizations* (source: USM website; https://www.usmd.edu/institutions/map/).

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Environmental sustainability has become an increasingly central domain of inquiry across higher education systems worldwide, prompting scholars to examine not only what institutions are doing but also how they are organizationally capable of responding to global sustainability imperatives. This chapter synthesizes the major bodies of literature relevant to sustainability transformation in higher education institutions (HEROs), including recent scholarship that explores how universities navigate environmental demands, develop sustainability strategies, engage in organizational change, deploy dynamic capabilities, and evolve innovation and entrepreneurial ecosystems. The review proceeds through five interconnected areas: (1) sustainability in HEROs, (2) organizational change for sustainability, (3) strategic sustainability and resource-based perspectives, (4) dynamic capabilities in higher education, and (5) sustainability-driven innovation and entrepreneurship. Together, these strands provide the conceptual backdrop for understanding the complexity of sustainability transitions in HEROs. This chapter synthesizes these domains to build a comprehensive understanding of how HEROs respond to sustainability pressures and build capabilities that drive innovation, entrepreneurship, and performance.

2.2 Sustainability in Higher Education Institutions

The literature on sustainability in HEROs has expanded significantly over the past decade, reflecting the growing global consensus that universities must play a transformative role in addressing climate change, biodiversity loss, pollution, and social inequities. Earlier work established the foundational arguments for universities as sustainability leaders (Cortese, 2003; Sterling, 2004), but more recent studies emphasize that sustainability has become deeply embedded in the international policy and governance landscape. Universities now operate within an ecosystem of sustainability frameworks that includes the UN Sustainable Development Goals (SDGs), the Times Higher Education Impact Rankings, and the AASHE STARS dataset. Recent analyses highlight the proliferation of sustainability assessment systems across regions and the competitive pressures they generate for institutional reputation and student attraction (Findler et al., 2019; Alghamdi & den Heijer, 2021).

Despite the proliferation of sustainability rhetoric in HEROs, the literature consistently shows a gap between institutional commitment and implementation. Studies conducted between 2020 and 2024 repeatedly document that universities frequently articulate ambitious climate and sustainability goals without achieving the structural coherence and cross-campus integration required to deliver on those commitments (Leal Filho et al., 2022; Fissi et al., 2021; Agyeman & Newell, 2024). This “aspiration–action gap” arises from barriers such as limited funding, fragmented governance structures, competing strategic priorities, weak coordination between academic and operational units, and insufficient faculty incentives. In particular, the decentralized decision-making typical of many HEROs complicates cross-unit collaboration, making it difficult to implement institution-wide sustainability strategies.

Contemporary studies also highlight regional differences. For example, European universities often benefit from national policy frameworks and long-term public funding that support sustainability initiatives, whereas HEROs in the Global South face challenges related to underfunding, resource scarcity, and infrastructure limitations but nonetheless demonstrate innovation in community-engaged sustainability programs (Aguirre-Bielschowsky et al., 2021; Salvia et al., 2019). In the United States, competitive pressures and philanthropic influences shape sustainability trajectories, often leading to a reliance on student activism and voluntary commitments rather than mandated systemic action (Barth & Rieckmann, 2020).

2.3 Organizational Change and Sustainability Transformation in HEROs

Organizational change has become an essential lens for understanding sustainability transitions in universities because HEROs exhibit structural and cultural characteristics that make transformation challenging. Classic research highlights the tendency of universities to function as loosely coupled systems with strong professional autonomy, entrenched disciplinary silos, and complex shared governance structures (Kezar, 2014; Mintzberg, 1979). Recent scholarship deepens this picture by examining how sustainability intersects with these organizational features. Studies from the past five years indicate that sustainability transformations in HEROs require not only top-down mandates but also bottom-up engagement and lateral coordination across academic and operational units (Rieg et al., 2021; Trencher et al., 2020). Leadership commitment is frequently cited as a necessary but insufficient condition for meaningful change. Success depends on distributed leadership models, inclusive governance processes, and the ability to mobilize broad coalitions of faculty, staff, students, and external partners (Giovannoni & Fabietti, 2022).

Applying organizational change frameworks to sustainability, recent work emphasizes the importance of sensemaking processes in shaping how HERO stakeholders understand sustainability goals and the challenges associated with implementing them. Sustainability initiatives often require rethinking institutional identities and academic norms, which leads scholars to argue for culturally informed change strategies that promote shared understanding and collective ownership of sustainability visions (Marshall et al., 2023).

Finally, recent work on transformative learning provides insight into the deeper pedagogical and cultural dimensions of sustainability transitions. Universities that successfully integrate sustainability tend to encourage reflexive, interdisciplinary, and problem-based learning approaches that challenge traditional academic boundaries (Trevisan et al., 2024). These approaches foster institutional cultures that are more adaptive, collaborative, and aligned with sustainability goals.

2.4 Strategic Sustainability and Resource-Based Perspectives

Strategic management perspectives illuminate the ways in which HEROs incorporate sustainability into their long-term strategic agendas. The natural resource–based view (NRBV) and contemporary literature on strategic sustainability frame environmental performance as a potential source of strategic advantage, not only for private firms but also for universities.

Several recent studies emphasize that sustainability can enhance institutional competitiveness by improving brand reputation, attracting mission-driven students, securing donor and grant funding, and bolstering global rankings (Roy et al., 2022; Alshuwaikhat & Abubakar, 2021). Increasingly, universities are incorporating sustainability into strategic plans and integrating it with risk management, investment planning, and campus development (Gunnlaugsson & Þórhallsson, 2021).

Recent literature also links sustainability strategy to the development of intangible assets, such as cross-disciplinary faculty collaboration, sustainable campus infrastructures, and community partnerships (Fernandez & Nagesh, 2023). These assets align with NRBV principles: rare, valuable, difficult to imitate, and contribute to institutional differentiation.

However, studies caution that sustainability strategies often lack the coordination and resource allocation needed to become fully institutionalized. Strategy execution challenges arise from insufficient alignment across university units, short-term funding mechanisms, and the absence of sustainability metrics in leadership evaluation systems (Fissi et al., 2021; Leal Filho et al., 2022).

2.5 Dynamic Capabilities in Higher Education

Dynamic capabilities theory (DCT), long influential in corporate strategy research, has only recently been taken up in higher education research. Recent work suggests that universities facing environmental turbulence including climate change, digital transformation, and shifting societal expectations, must develop dynamic capabilities to adapt effectively.

Emerging studies between 2021 and 2025 indicate that universities with strong sensing capabilities actively monitor sustainability trends, engage with diverse stakeholders, and leverage data to anticipate and respond to emerging challenges (Gohr et al., 2023; Shen et al., 2025). Seizing capabilities involve the ability to mobilize resources, develop sustainability programs, secure funding, and implement initiatives. Reconfiguring capabilities reflect the institution's ability to restructure governance, redesign curricula, modernize infrastructures, and cultivate interdisciplinary collaboration.

Research applying DCT to HEROs demonstrates that dynamic capabilities are crucial for achieving sustainability-driven innovation and institutional performance. For example, Guerrero (2024) shows that dynamic capabilities help universities advance their "third mission," including socially oriented innovation and community engagement. Similarly, studies on green digital transformation highlight the role of dynamic capabilities in enabling universities to integrate environmental sustainability with digital innovation agendas (Shen et al., 2025). As sustainability demands intensify, the development of dynamic capabilities appears to be a decisive factor distinguishing HEROs that implement transformative sustainability changes from those that make only incremental improvements.

2.6 Innovation, Entrepreneurship, and Sustainability in HEROs

Finally, there is growing recognition of the role of HEROs as catalysts of sustainability-driven innovation and entrepreneurship. The entrepreneurial university literature, grounded in the Triple Helix model of university–industry–government, has been reinvigorated by contemporary interest in sustainability transitions.

Recent studies document how universities are increasingly integrating sustainability into entrepreneurship education, incubators, accelerators, and innovation labs (Dote-Pardo et al., 2025; Meek et al., 2023). HEROs serve not only as knowledge hubs but as “living laboratories” where sustainability-oriented technologies and social innovations are developed and tested. These innovations encompass renewable energy projects, green building practices, sustainable mobility, circular economy initiatives, and climate adaptation solutions.

Innovation ecosystems have also become more complex and interconnected. Universities are building partnerships with municipalities, NGOs, startups, and global organizations to co-create sustainable solutions (Neudert et al., 2024). Such ecosystem collaborations broaden the scope of innovation beyond technology development to include policy experimentation, community engagement, and place-based approaches to sustainability.

Finally, studies highlight the distinctive features of sustainability entrepreneurship in HEROs. Unlike traditional entrepreneurship, sustainability entrepreneurship often seeks social and environmental impact as well as economic value. Recent analyses identify tensions that arise when universities attempt to balance sustainability commitments with commercial objectives, prompting calls for more inclusive and mission-driven models of innovation (Garomssa, 2025).

2.7 Summary of Gaps and Contributions

The current literature demonstrates both the breadth of research on sustainability in HEROs and the fragmentation among its conceptual approaches. Despite rapid advances, several gaps remain:

- Research often examines sustainability strategy, organizational change, dynamic capabilities, or innovation in isolation, rather than through an integrated framework.
- Limited empirical work examines dynamic capabilities specifically in HEROs, especially in the context of sustainability.
- Few studies adopt prospective scenario analysis designs capable of linking institutional conditions to sustainability outcomes over time.
- Comparative international research remains underdeveloped, despite significant regional differences.
- The relationship between sustainability strategy and sustainability-driven innovation and entrepreneurship is still emerging.

This dissertation addresses these gaps by integrating multiple theoretical perspectives, using a rigorous SD modeling design, and focusing on both U.S. and international HEROs to examine how sustainability strategy, organizational change, dynamic capabilities, and innovation ecosystems interact to shape sustainability performance.

CHAPTER 3

THEORETICAL FRAMEWORK

3.1 Overview

Environmental sustainability in higher education institutions (HEROs) is a complex, multi-layered phenomenon that spans organizational behavior, strategic management, innovation systems, and societal transition studies. This chapter presents the theoretical foundations guiding the dissertation. Five main theoretical domains frame the inquiry: (1) dynamic capabilities theory, (2) the natural resource–based view and strategic sustainability, (3) organizational change theory, (4) institutional theory, and (5) entrepreneurial university and innovation ecosystem theory. Each of these perspectives offers a distinct but complementary lens for examining how HEROs make sense of sustainability pressures, adapt their internal processes, and generate innovation and entrepreneurship aligned with environmental goals. Recent research (e.g., Correggi et al., 2024; Gohr et al., 2023; Neudert et al., 2024) emphasizes the importance of integrating these perspectives to understand sustainability transformation as both an internal organizational process and an externally shaped institutional phenomenon. The integration of these frameworks allows for a holistic conceptualization of HEROs not only as organizations reacting to sustainability pressures but also as agents capable of shaping sustainability transitions through knowledge production, innovation, and partnerships.

3.2 Dynamic Capabilities Theory Relevance to Sustainability in HEROs

Dynamic capabilities theory (DCT), first formalized by Teece et al. (1997), describes an organization's ability to sense opportunities and threats, seize them through strategic action, and reconfigure assets and structures to maintain alignment with changing conditions. More recent formulations (Teece, 2007) emphasize the microfoundations of these capabilities, such as learning systems, organizational culture, managerial cognition, and cross-functional collaboration. In the context of sustainability, DCT has evolved into what some scholars term "sustainable dynamic capabilities," highlighting organizational processes that support adaptation to environmental, social, and regulatory pressures (Correggi et al., 2024; Cristofaro et al., 2025). These capabilities allow organizations to anticipate climate risks, identify sustainability opportunities, and reconfigure structures and routines to advance sustainability goals.

Higher education research has only recently begun to apply DCT systematically. Guerrero (2024), for example, demonstrates how dynamic capabilities shape universities' ability to pursue their "third mission" of societal impact. Shen et al. (2025) apply DCT to understand how universities develop green digital innovation through the interplay of leadership and organizational learning. Abunaser et al. (2025) show that administrative dynamic capabilities influence awareness and adoption of new technologies among students.

In HEROs, dynamic capabilities emerge in actions such as anticipating climate policy changes, responding to stakeholder sustainability demands, reorganizing governance to support sustainability offices or climate councils, and reallocating resources to interdisciplinary sustainability programs. These activities reflect the sensing, seizing, and reconfiguring dimensions of DCT. Universities with strong dynamic capabilities are more likely to align sustainability strategy with innovation and performance outcomes, making DCT a central theoretical lens in this dissertation.

3.3 Strategic Sustainability and the Natural Resource–Based View

Dynamic capabilities theory explains how organizations change but does not sufficiently address why sustainability becomes strategically important. The natural resource–based view (NRBV) offers this perspective by arguing that firms, and analogously HEROs, gain competitive advantage by developing capabilities related to pollution prevention, product stewardship, and sustainable development (Hart, 1995; Hart & Dowell, 2011).

Recent studies show that sustainability has become a strategic differentiator for universities. Sustainability impacts student recruitment, research funding, global visibility, accreditation, and partnerships (Fernandez & Nagesh, 2023; Roy et al., 2022). NRBV provides a lens for understanding how HEROs value and mobilize sustainability-related resources, including sustainable campus infrastructure, interdisciplinary expertise, climate research centers, and partnerships with government and industry. However, strategy alone does not ensure implementation. NRBV complements DCT by explaining how sustainability becomes a strategic priority, while DCT explains how capabilities emerge to execute that strategy. Together, they create a powerful theoretical foundation for understanding capability-driven sustainability transformation in HEROs.

3.4 Organizational Change and Sustainability Transformation in HEROs

Shared governance, professional autonomy, entrenched disciplinary silos, and the coexistence of academic and administrative cultures create significant organizational complexity in HEROs (Mintzberg, 1979; Kezar, 2014). Recent literature highlights that sustainability transformation requires not only operational and structural adjustments but also cultural and behavioral change (Marshall et al., 2023; Rieg et al., 2021). Contemporary research shows that sustainability transformations in universities depend heavily on distributed leadership, cross-department collaboration, and opportunities for stakeholder participation (Giovannoni & Fabietti, 2022). Change does not proceed linearly; instead, it involves cycles of sensemaking, alignment, resistance, and adaptation. Trevisan et al. (2024) argue that transformative sustainability learning is central to fostering organizational change, while Burford et al. (2021) underscore the importance of reflexivity and values-based leadership. These insights suggest that sustainability in HEROs cannot be understood solely through policy frameworks; instead, it must be examined through the organizational processes that shape action. In this dissertation, organizational change theory helps explain the internal mechanisms through which sustainability strategies translate into capability development and performance.

3.5 Institutional Theory and External Sustainability Pressures

Institutional theory provides a macro-level frame for understanding how HEROs respond to coercive (regulatory), normative (professional), and mimetic (peer-driven) pressures (Scott, 2014). Sustainability in higher education has become increasingly institutionalized through global initiatives such as the SDGs, sustainability rankings, government mandates, philanthropic priorities, and student activism.

Recent studies emphasize that sustainability in HEROs is driven by a complex interplay of institutional logics, field-level norms, and legitimacy concerns (Agyeman & Newell, 2024; Salvia et al., 2019). Universities face expectations not only to reduce their environmental footprint but also to lead societal sustainability transitions.

This institutional perspective helps to explain why HEROs sometimes adopt sustainability practices symbolically to maintain legitimacy rather than substantively. It also helps account for global variation in sustainability outcomes, as HEROs in Europe, North America, Asia, and the Global South operate under different regulatory, cultural, and economic regimes (Neudert et al., 2024). Institutional theory therefore situates the strategic and organizational dynamics examined in this dissertation within broader socio-political structures.

3.6 Entrepreneurial University and Innovation Ecosystem Theory

The entrepreneurial university concept, rooted in the Triple Helix model (university–industry–government), positions HEROs as catalysts for innovation and regional development (Etzkowitz & Leydesdorff, 2000). Recent scholarship expands this model to incorporate sustainability, green entrepreneurship, and social innovation (Meek et al., 2023; Dote-Pardo et al., 2025). In the last five years, studies have shown that universities are increasingly integrating sustainability into entrepreneurship centers, incubators, accelerators, and innovation partnerships. This involves campus living labs, climate innovation hubs, and sustainability research clusters that test solutions for renewable energy, mobility, waste reduction, and climate adaptation (Trevisan et al., 2024).

Innovation ecosystem theory (Neudert et al., 2024) emphasizes the interdependence of multiple actors—industry, NGOs, government, investors, and communities—in advancing sustainability transitions. HEROs often function as orchestrators in these ecosystems by producing knowledge, providing infrastructure for experimentation, and convening stakeholders. In this dissertation, entrepreneurial university and innovation ecosystem theory link sustainability strategy and dynamic capabilities to innovation and entrepreneurship outcomes.

3.7 Integrated Conceptual Model

Bringing these strands together, the dissertation proposes an integrated conceptual model in which:

- Institutional pressures motivate HEROs to adopt sustainability strategies.
- NRBV explains how sustainability becomes a strategic priority.
- Organizational change processes shape the internal conditions that support capability development.
- Dynamic capabilities enable HEROs to sense sustainability risks and opportunities, seize them through strategic actions, and reconfigure structures to support sustainability.
- Innovation ecosystem and entrepreneurial university theory explain the resulting sustainability-driven innovation and entrepreneurship outcomes.

This integrated model guides the development of the research methodology, results and discussion presented in the following chapters.

CHAPTER 4

METHODOLOGY

4.1 Overview

The purpose of this chapter is to present the methodological design of the study, which examines how higher education institutions (HEROs) develop organizational change processes, sustainability strategies, and dynamic capabilities that influence innovation and entrepreneurship outcomes. Because sustainability transformation in HEROs is a multidimensional and context-dependent phenomenon, this methodology adopts an approach that accommodates both breadth and depth. A modeling-based prospective scenario design is used to integrate quantitative analysis of relationships among core constructs with qualitative insights that illuminate institutional processes, contextual dynamics, and pathways of influence. This chapter outlines the rationale for the research design, describes the study data sources, details the development of the prospective modeling approach using SD, and explains the development of scenarios based on the dissertation's research questions.

4.2 Research Design

This dissertation adopts a System Dynamics (SD) modeling approach to investigate how higher education institutions (HEROs) develop organizational capabilities for environmental sustainability, manage organizational change, and generate sustainability-oriented innovation and entrepreneurship over time. Sustainability transformation in universities is widely recognized as a complex, nonlinear process shaped by feedback loops, delays, path dependence, and interactions between strategy, culture, resources, and external pressures. Traditional linear or cross-sectional empirical methods are often ill-suited to capture these dynamics, particularly when outcomes emerge gradually and indirectly through reinforcing and balancing processes. System Dynamics provides a rigorous methodological framework for addressing these challenges by explicitly representing dynamic feedback structures and simulating system behavior across extended time horizons (Sterman, 2000, 2018; Schwaninger, 2019).

The methodological objective of this study is not point-prediction, but theory-driven explanation and policy exploration. By integrating organizational theory with empirical sustainability data, the SD model enables systematic examination of how alternative strategic and governance choices shape sustainability trajectories in HEROs. This chapter describes the research design, model structure, data sources, calibration strategy using AASHE STARS data, validation procedures, and the development of policy scenarios aligned with the study's research questions.

Environmental sustainability in HEROs unfolds through long-term institutional processes rather than short-term cause-and-effect relationships. HEROs are complex adaptive systems characterized by shared governance, professional autonomy, siloed structures, and competing missions. Sustainability initiatives often face delayed payoffs, resistance to change, and resource constraints, while early successes can generate reinforcing feedback through legitimacy, learning, and investment. System Dynamics is particularly well suited to this context because it models systems as interconnected stocks, flows, and feedback loops, allowing researchers to examine how structural features generate observed behavior over time (Sterman, 2000). Recent sustainability and organizational research increasingly emphasize the value of SD for studying sustainability transitions, institutional learning, and innovation systems (Bala et al., 2017; Turner et al., 2023). In higher education research, SD has been applied to enrollment dynamics, financial sustainability, and strategic planning, yet its application to sustainability capability development remains limited.

This dissertation addresses that gap by applying SD to model sustainability transformation as a capability-driven, feedback-rich process within HEROs.

4.3 Research Questions

The study is guided by five research questions that explore how HEROs conceptualize, structure, and operationalize sustainability. Although these questions were formulated theoretically in Chapter 1, the methodological aim here is to translate them into a set of testable empirical relationships. These quantitative hypotheses include expected positive associations between sustainability strategy and dynamic capabilities; between dynamic capabilities and sustainability innovation; and between innovation and institutional performance indicators such as reputation and sustainability rankings. Furthermore, the analysis examines whether organizational change processes mediate the relationship between sustainability strategy and institutional performance, and whether institutional characteristics (e.g., national context, public vs. private governance) moderate certain relationships.

The use of hypotheses derived from dynamic capabilities theory, strategic sustainability literature, and organizational change frameworks is consistent with contemporary expectations for quantitative rigor in sustainability management research (Gohr et al., 2023; Shen et al., 2025). Consistent with Chapters 1–3, the methodology addresses the following research questions. The quantitative component tests relationships derived from Dynamic Capabilities Theory, Institutional Theory, Strategic Sustainability, and Organizational Change Theory.

- RQ1: How do HEROs conceptualize and integrate environmental sustainability into their institutional strategies and governance structures?

- RQ2: What dynamic capabilities do HEROs develop to support sustainability transformation, and how do these capabilities vary across institutional contexts?
- RQ3: How do organizational change mechanisms facilitate or hinder the implementation of sustainability strategies in HEROs?
- RQ4: How do sustainability strategies and dynamic capabilities influence sustainability-driven innovation and entrepreneurship within HEROs?
- RQ5: How do sustainability transformation processes differ between U.S. and international institutions?

4.4 Modeling Design and Structure

The study employs a theory-driven System Dynamics research design, centered on the construction, calibration, and simulation of a stock-and-flow model representing sustainability transformation in HEROs. Rather than testing hypotheses through statistical inference, the design emphasizes model-based reasoning, behavioral pattern reproduction, and policy scenario experimentation. This approach is consistent with established SD research practices in strategy and sustainability studies (Sterman, 2018; Schwaninger & Groesser, 2020).

The modeling process begins with the conceptual framework developed in Chapter 3, which integrates dynamic capabilities theory, strategic sustainability, organizational change theory, institutional theory, and entrepreneurial university perspectives. This framework is translated into a causal loop diagram and then formalized as a stock-and-flow structure suitable for simulation. The resulting model captures accumulations such as sustainability strategic commitment, dynamic capabilities, organizational alignment, sustainability-oriented innovation, and institutional legitimacy, along with flows that govern how these stocks evolve over time.

The SD model represents sustainability transformation in HEROs through five core "stocks". Sustainability strategic commitment captures the degree to which sustainability is embedded in institutional strategy, leadership priorities, and governance structures. Dynamic capabilities represent the institution's capacity to sense sustainability challenges and opportunities, seize them through coordinated action, and reconfigure organizational resources and routines. Organizational alignment and culture reflect the extent to which sustainability values and practices are internalized across academic and administrative units. Sustainability-oriented innovation and entrepreneurship capture the accumulation of sustainability-focused research, curricular innovation, startups, partnerships, and applied solutions. Institutional legitimacy and reputation represent external recognition and credibility derived from sustainability performance.

These stocks are linked through reinforcing and balancing feedback loops. Reinforcing loops capture processes such as how sustainability investments build capabilities, capabilities enable innovation, innovation enhances legitimacy, and legitimacy strengthens future strategic commitment. Balancing loops capture constraints such as limited resources, organizational resistance, leadership turnover, and diminishing returns at higher levels of maturity. This structure reflects well-documented patterns in sustainability and organizational change research, including early slow progress, mid-stage acceleration, and eventual plateauing (Sterman, 2000; Marshall et al., 2023). Appendix A documents the development logic and structure of the SD model that is used in this investigation including the corresponding SD code.

4.5 Data Sources, Model Calibration and Validation

The SD model is informed and calibrated using AASHE's Sustainability Tracking, Assessment & Rating System (STARS) as the primary empirical data source. STARS provides standardized, longitudinal, and institution-level data on sustainability performance across academics, engagement, operations, planning and administration, and innovation and leadership. While STARS does not directly measure latent organizational capabilities, it offers rich proxies for observable manifestations of strategy, alignment, innovation, and institutionalization. STARS data are particularly appropriate for SD calibration because they capture both breadth and depth of sustainability implementation and, for many institutions, include multiple submissions over time. These features enable the construction of time-based indicators aligned with the model's stocks and flows, supporting dynamic rather than static calibration (AASHE, 2023; Findler et al., 2019). Calibration focuses on ensuring that simulated behavior reproduces plausible sustainability trajectories, rather than achieving exact numerical fit. Following best practices in System Dynamics, calibration emphasizes structural validity, behavioral realism, and policy relevance (Barlas, 1996; Sterman, 2018).

STARS category and credit scores are mapped to model stocks through theoretically grounded proxy indices. STARS indicators are not treated as direct measures of organizational capabilities but as empirically grounded proxies that reflect observable manifestations of underlying strategic, cultural, and innovation processes. This approach is consistent with best practices in System Dynamics, where latent stocks are calibrated using multiple indirect indicators rather than single observed variables. Table 4.1 maps AASHE STARS categories and credits to the SD model stocks and auxiliaries, providing transparency, defensibility, and replicability.

Table 4.1: Mapping AASHE STARS Indicators to System Dynamics Model Constructs
(source: prepared for this research)

SD Model Construct	Primary STARS Category / Credits	Rationale for Mapping
Sustainability Strategic Commitment (SSC)	Planning & Administration (PA): Sustainability Planning, Climate Action Plans, Targets & Tracking, Governance Coordination	These credits reflect formal commitments, leadership intent, goal-setting, and accountability mechanisms, which collectively represent institutional strategic commitment to sustainability.
Dynamic Capabilities (DC)	Composite proxy derived from: (1) rate of change in overall STARS score across submissions; (2) balance across Operations, Academics, Engagement, and PA categories; (3) assessment and continuous improvement credits	Dynamic capabilities are not directly observable in STARS. They are inferred from learning capacity, cross-domain coordination, and improvement speed, all of which are reflected indirectly through STARS performance patterns.
Organizational Alignment & Culture (OAC)	Planning & Administration: Coordination, Incentives, Assessment; Engagement: Campus Engagement, Employee Engagement, Student Participation	These indicators capture internal alignment, shared norms, participation, and institutionalization of sustainability practices across organizational units.

SD Model Construct	Primary STARS Category / Credits	Rationale for Mapping
Sustainability-Oriented Innovation & Entrepreneurship (SIE)	Innovation & Leadership (I&L); Academics: Research, Curriculum Innovation; Engagement: Community Partnerships	These credits directly capture experimentation, interdisciplinary innovation, applied sustainability solutions, and entrepreneurial activity within and beyond the institution.
Institutional Legitimacy & Reputation (ILR)	Overall STARS Score; Innovation & Leadership narrative recognition; (optional) Platinum/Gold thresholds	STARS ratings function as a reputational signal to external stakeholders, funders, students, and peers, reinforcing legitimacy and visibility.
External Institutional Pressure (Auxiliary)	Exogenous (not directly from STARS); inferred from gaps between institutional performance and peer/target benchmarks	Pressure is operationalized as a function of perceived underperformance relative to sustainability norms and expectations reflected in STARS benchmarking.
Sustainability Investment (Auxiliary)	Indirect proxy using breadth of implemented credits,	While STARS does not report budgets, the scope and diversity of implemented initiatives

SD Model Construct	Primary STARS Category / Credits	Rationale for Mapping
	staffing/coordination credits, and leadership support narratives	provide a reasonable proxy for investment intensity.
Organizational Resistance (Auxiliary)	Inferred from category imbalance (e.g., strong operations but weak academics/engagement), stagnation across submissions	Resistance is modeled as latent inertia, inferred from uneven adoption and stalled diffusion across institutional domains.

Planning and Administration indicators related to sustainability planning, governance, targets, and assessment are used to calibrate sustainability strategic commitment. Innovation and Leadership indicators, supplemented by relevant Academics and Engagement credits, inform the sustainability-oriented innovation stock. Organizational alignment is inferred from engagement, coordination, and assessment-related indicators, while institutional legitimacy is proxied by overall STARS scores and leadership-oriented recognition components.

Dynamic capabilities, which are not directly observable, are calibrated as a latent construct inferred from the rate of improvement across STARS submissions, balance across categories, and presence of continuous improvement mechanisms. All proxies are normalized to a common scale and used as reference modes against which simulated trajectories are compared.

Calibration proceeds iteratively. Initial parameter ranges are established from the literature and empirical distributions of STARS scores. Model parameters governing capability development, alignment formation, innovation generation, resistance, and resource constraints are adjusted so simulated trajectories fall within observed ranges and reproduce characteristic patterns such as delayed innovation payoffs and plateauing at higher maturity levels. Sensitivity analysis is used to identify high-leverage parameters and refine plausible ranges.

Model validation follows established SD principles, emphasizing confidence in structure and behavior rather than statistical goodness-of-fit (Sterman, 2000; Barlas, 1996). Structural validation ensures that causal relationships and feedback loops are consistent with theory and empirical sustainability research. Behavioral validation assesses whether the model reproduces observed patterns in STARS data, such as gradual improvement, acceleration following governance reforms, and stagnation under high resistance or resource constraints. Additional validation tests include extreme condition testing, sensitivity analysis, and cross-validation using different subsets of institutions and institutional archetypes. These procedures strengthen confidence that the model captures essential system behavior and can support meaningful policy analysis. Appendix B provides details of the SD model calibration and validation using the AASHE/STARS database.

4.6 Policy Scenario Development

Once calibrated and validated, the SD model is used to explore five policy scenarios, each aligned with one of the dissertation's research questions. These scenarios are implemented as parameter changes or time-based interventions and are run over a period of 20 years to allow enough time for interventions to be planned and executed and examine their medium-to-long-term consequences and unintended effects.

The first scenario examines enhanced sustainability governance and strategic integration, representing reforms such as board-level oversight and integrated planning. The second focuses on deliberate dynamic capability building through analytics, training, and cross-functional implementation capacity. The third explores organizational change and cultural transformation interventions designed to reduce resistance and accelerate alignment. The fourth simulates the development of a sustainability innovation ecosystem, such as living labs and incubators, to amplify innovation and legitimacy feedbacks. The fifth compares U.S. and international institutional contexts by varying parameters related to leadership stability, funding constraints, and external pressure. Scenario outcomes are evaluated using trajectories of the core stocks and STARS-aligned proxy indices, enabling interpretation in both theoretical and practical terms.

Policy Scenario 1: Governance and Strategy Integration Push

Policy Scenario 1 represents an intervention in which environmental sustainability is formally integrated into core governance and strategic decision-making structures. Within the System Dynamics model, this scenario is operationalized through increased rates of strategy reinforcement, reduced strategic decay, and stronger coupling between institutional legitimacy and strategic commitment. These changes reflect mechanisms such as governing board oversight, executive accountability, and the embedding of sustainability into institutional planning and performance systems. The scenario is designed to test the extent to which institutionalizing sustainability at the highest levels of authority stabilizes long-term commitment and reduces vulnerability to leadership turnover, while holding cultural and capability conditions broadly constant.

Policy Scenario 2: Dynamic Capability Building

Policy Scenario 2 focuses on deliberate investments in dynamic capabilities related to sustainability, including organizational learning, cross-functional coordination, data and analytics, and adaptive management processes. In the model, this intervention is represented by higher capability development rates, reduced capability erosion, and shorter delays between learning and implementation. The scenario isolates the effects of capability accumulation by maintaining baseline governance and cultural structures, allowing examination of whether enhanced execution capacity alone can drive sustained sustainability outcomes. This design reflects real-world interventions such as professional development programs, sustainability analytics platforms, and structured experimentation initiatives.

Policy Scenario 3: Organizational Change and Cultural Transformation

Policy Scenario 3 emphasizes organizational change and cultural transformation as the primary levers of sustainability advancement. This scenario is implemented in the model through reduced organizational resistance, higher rates of cultural alignment, and lower drift in shared sustainability norms. These mechanisms capture interventions such as participatory change processes, faculty and staff engagement, leadership communication, and sensemaking activities. By holding governance authority and investment levels close to baseline, the scenario is designed to test whether cultural coherence and reduced resistance can independently generate sustained improvements in sustainability performance and system stability.

Policy Scenario 4: Sustainability Innovation Ecosystem Accelerator

Policy Scenario 4 models an aggressive strategy centered on accelerating sustainability-oriented innovation and entrepreneurship through ecosystem development. In the model, this is represented by increased innovation productivity, stronger visibility and legitimacy amplification effects, and enhanced investment feedback from innovation success. The scenario captures interventions such as sustainability incubators, living laboratories, external partnerships, and applied research platforms. This design allows assessment of how rapidly amplifying reinforcing loops between innovation and legitimacy affects long-term sustainability outcomes, while also revealing potential imbalances if governance, capabilities, or culture do not scale in parallel.

Policy Scenario 5: Institutional Context Regimes (U.S. versus International)

Policy Scenario 5 introduces institutional context as a structural condition shaping system behavior rather than as a policy lever. Two parameter regimes are specified: a U.S.-like context characterized by higher leadership turnover, stronger competitive pressure, and greater responsiveness to legitimacy signals; and an international public-sector context characterized by greater governance stability, stronger regulatory pressure, and longer planning horizons. This scenario enables comparative analysis of how identical policy interventions produce different dynamic outcomes depending on institutional context, thereby addressing external validity and generalizability concerns in sustainability strategy research.

4.7 Additional Methodological Considerations

For consistency and replicability purposes, this research relies primarily on publicly available and aggregated institutional data. No individual-level data are collected, and institutions are anonymized in comparative analysis where appropriate. All modeling assumptions, data transformations, and parameter choices are transparently documented to ensure replicability and ethical research practice. System Dynamics models necessarily simplify reality and depend on assumptions regarding structure and parameter values. STARS data reflect self-reported information and may vary in completeness across institutions and time. The SD model is designed for explanation and learning in a comparative/relative sense rather than precise prediction. These limitations are acknowledged and addressed through sensitivity analysis, transparent documentation, and careful interpretation of results.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Overview

This chapter presents and interprets the results of the System Dynamics simulations conducted to address the five research questions guiding this dissertation. Using a calibrated stock-and-flow model grounded in AASHE STARS data and organizational theory, the analysis explores how alternative governance, capability, change management, innovation, and contextual policies shape long-term sustainability transformation in higher education institutions (HEROs). Rather than evaluating isolated interventions, the results illuminate how sustainability outcomes emerge from dynamic interactions among strategy, capabilities, culture, resources, and external pressures over time. Across all scenarios, the findings consistently demonstrate that sustainability transformation in HEROs is a path-dependent, feedback-driven process. Interventions that strengthen reinforcing loops and weaken constraining forces produce qualitatively different long-term trajectories, even when short-term differences appear modest. This chapter integrates results across scenarios to identify dominant leverage points, explain observed dynamics, and draw implications for theory and practice.

5.2 Summary of Results

5.2.1 Baseline Dynamics: Sustainability Transformation Without Policy Intervention

Under baseline conditions, the model produces trajectories characterized by gradual improvement followed by plateauing, a pattern frequently observed in empirical STARS data. Sustainability strategic commitment grows slowly as institutions respond to external pressure and internal advocacy, but progress is intermittently disrupted by leadership turnover and competing priorities.

Sustainability investment fluctuates, reflecting the absence of strong governance mechanisms linking commitment to resource allocation. Dynamic capabilities accumulate incrementally but remain insufficient to drive large-scale innovation. Organizational alignment improves unevenly across institutional domains, leading to persistent silos. As a result, sustainability-oriented innovation and entrepreneurship increase modestly but fail to reach levels associated with institutional transformation or sector leadership. Institutional legitimacy improves, but not enough to trigger strong reinforcing feedback through investment and strategic renewal. This baseline behavior establishes a critical reference point: incremental sustainability progress is possible without deliberate intervention, but transformation is unlikely. The baseline reinforces the premise that sustainability success in HEROs cannot be assumed to emerge organically and requires intentional structural change.

5.2.2 Scenario 1: Governance and Strategy Integration Push

The first policy scenario examines the effects of strengthening sustainability governance and integrating sustainability into core institutional strategy. Simulation results show that this intervention produces a step change in long-term sustainability performance, even though short-term gains appear limited. Governance integration stabilizes sustainability strategic commitment by reducing decay associated with leadership turnover and fragmented authority. As a result, investment becomes more consistent and strategically aligned. This stability accelerates the accumulation of dynamic capabilities, particularly those related to coordination, learning, and implementation across organizational boundaries.

The most striking effect occurs downstream. Sustainability-oriented innovation initially responds slowly, reflecting inherent delays between governance reform and operational outcomes. However, once capability and alignment thresholds are reached, innovation accelerates sharply, reinforcing institutional legitimacy and feeding back into stronger strategic commitment. Over a 20-year horizon, institutions under this scenario converge toward a significantly higher sustainability equilibrium than the baseline.

These results underscore governance and strategy as high-leverage structural interventions. Rather than directly producing innovation, governance integration creates the conditions under which other reinforcing processes can operate reliably. The findings align with organizational change and sustainability scholarship emphasizing institutionalization, accountability, and leadership continuity as prerequisites for durable transformation (Kezar, 2014; Lozano et al., 2015; Giovannoni & Fabietti, 2022).

5.2.3 Scenario 2: Dynamic Capability Building

The second scenario explores deliberate investment in dynamic capabilities, such as sensing sustainability opportunities, seizing them through coordinated action, and reconfiguring organizational resources. Compared to governance reform, capability-building interventions generate earlier observable impacts, particularly in innovation performance. Simulation results indicate that increasing the rate of capability development and shortening innovation delays accelerates sustainability-oriented innovation even in the absence of major governance reforms. Institutions develop a stronger ability to translate strategic intent into action, experiment with new solutions, and adapt to emerging challenges. However, without complementary governance integration, gains eventually slow as investment volatility and strategic drift reassert themselves.

This scenario highlights a critical insight: capabilities can compensate for weak governance in the short to medium term, but not indefinitely. Over longer horizons, institutions lacking strong strategic anchoring experience erosion of capabilities and diminished returns on innovation. The results support dynamic capabilities theory by demonstrating that capabilities are necessary but insufficient for sustained advantage without alignment to strategy and structure (Teece, 2007).

5.2.4 Scenario 3: Organizational Change and Cultural Transformation

The third scenario focuses on organizational change mechanisms designed to reduce resistance and strengthen cultural alignment, such as inclusive governance processes, faculty incentives, and coordinated change management. Results show that reducing resistance and cultural drift significantly enhances the effectiveness of both governance and capability investments. Under this scenario, organizational alignment grows more rapidly and diffuses more evenly across institutional domains. Reduced resistance allows sustainability initiatives to scale beyond early adopters, improving the conversion of investment and capability into innovation. While the direct effect on strategic commitment is moderate, the indirect effects on innovation and legitimacy are substantial.

Notably, this scenario reveals that resistance functions as a nonlinear constraint. Small reductions in resistance can produce disproportionate gains once alignment crosses critical thresholds. This finding reinforces organizational change theory arguments that cultural inertia, rather than lack of resources or vision, often represents the primary barrier to sustainability transformation in professional organizations such as universities (Mintzberg, 1979; Kotter, 1996).

5.2.5 Scenario 4: Sustainability Innovation Ecosystem Accelerator

The fourth scenario simulates the creation or expansion of a sustainability innovation ecosystem, including living labs, incubators, partnerships, and targeted seed funding. This intervention produces the most rapid gains in sustainability-oriented innovation and institutional legitimacy. Simulation results show strong reinforcing feedback between innovation, visibility, legitimacy, and investment. As innovation accelerates, legitimacy increases, attracting additional resources and external partnerships. These inflows further amplify innovation capacity, creating a virtuous cycle characteristic of entrepreneurial universities. However, the model also reveals that innovation ecosystems are fragile without upstream support. In the absence of governance integration and cultural alignment, innovation gains are vulnerable to saturation and legitimacy loss, particularly if innovation outcomes outpace strategic coherence. This underscores the importance of embedding innovation initiatives within broader institutional systems rather than treating them as standalone solutions.

5.2.6 Scenario 5: U.S. and International Contextual Regimes

The fifth scenario compares sustainability transformation trajectories under U.S. and international institutional contexts by varying parameters related to leadership stability, funding constraints, and external pressure. Results demonstrate that context shapes both the speed and robustness of sustainability transformation.

U.S.-like regimes, characterized by higher leadership turnover and greater funding volatility, exhibit faster initial innovation under favorable conditions but also greater susceptibility to regression. International public-sector regimes, with stronger policy mandates and more stable funding, display slower early progress but achieve more stable long-term outcomes.Importantly, the comparative analysis shows that policy effectiveness is context-dependent. Governance reforms are particularly powerful in volatile environments, while capability-building and innovation ecosystem strategies perform better in stable policy contexts. These findings caution against one-size-fits-all sustainability strategies and emphasize the need for context-sensitive design.

5.3 Discussion of Results

5.3.1 Policy Scenario 1 – Governance and Strategy Integration Push

Policy Scenario 1 evaluates the effects of strengthening governance structures and integrating environmental sustainability into core institutional strategy. In this scenario, sustainability priorities are formally embedded in executive decision-making, governing board oversight, performance management systems, and resource allocation processes. Unlike scenarios that emphasize cultural change (Scenario 3), capability accumulation (Scenario 2), or innovation ecosystem expansion (Scenario 4), this intervention focuses on stabilizing strategic commitment and reducing the erosion of sustainability priorities over time.

Simulation results indicate that governance and strategy integration produce a substantial and sustained increase in sustainability strategic commitment. As shown in Figure S1-1, strategic commitment grows more rapidly and reaches a higher long-run level under Scenario 1 than under baseline conditions. Importantly, commitment trajectories are smoother and more stable, reflecting reduced susceptibility to leadership turnover and shifting institutional priorities. Compared with Scenario 5's U.S.-like context, where commitment volatility is pronounced, Scenario 1 demonstrates how formal governance integration can buffer against instability. The results highlight governance as a structural lever that strengthens reinforcing feedback between legitimacy, investment, and strategic continuity. Governance integration significantly improves the conversion of strategic intent into sustained investment. As illustrated in Figure S1-2, sustainability investment increases earlier and remains consistently higher than in the baseline scenario. This reflects the role of governance mechanisms in protecting sustainability budgets, aligning incentives, and reducing short-term trade-offs that often undermine sustainability initiatives.

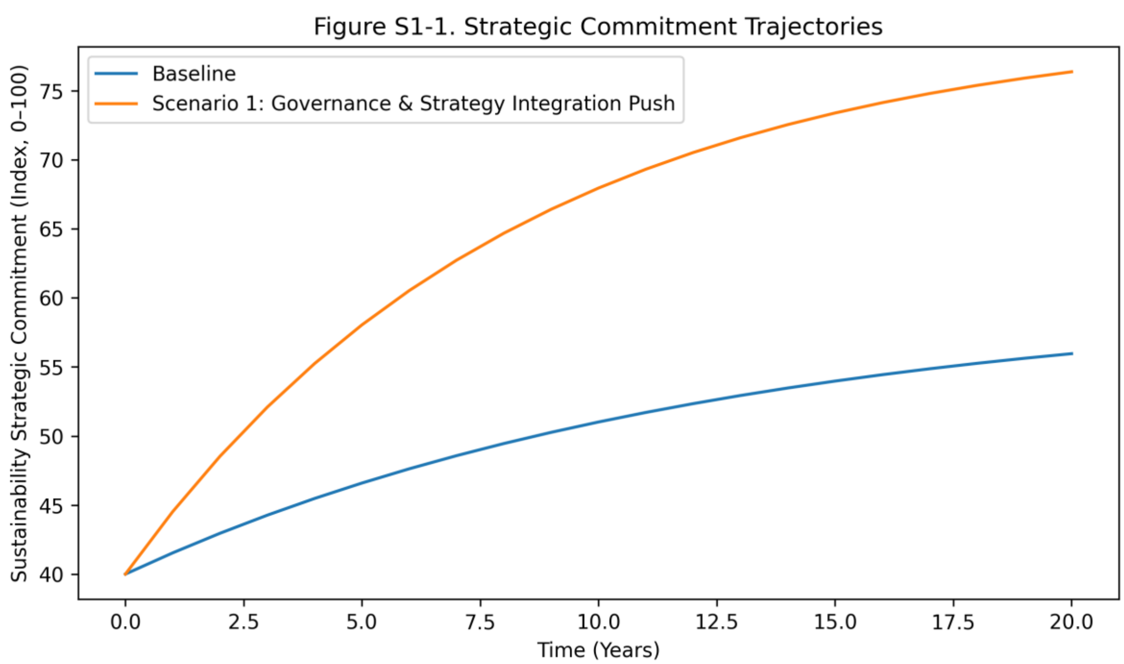

Figure S1-1: *Sustainability strategic commitment trajectories under baseline and governance integration scenarios. Governance and strategy integration increase the level and stability of strategic commitment by strengthening reinforcing feedback and reducing commitment decay.* (source: SD model results)

When compared to Scenario 2, where investment supports rapid capability development, Scenario 1 shows that governance-driven investment is steadier but less aggressive. This pattern suggests that governance integration creates a reliable investment floor, while other interventions may be required to accelerate investment growth beyond incremental levels.

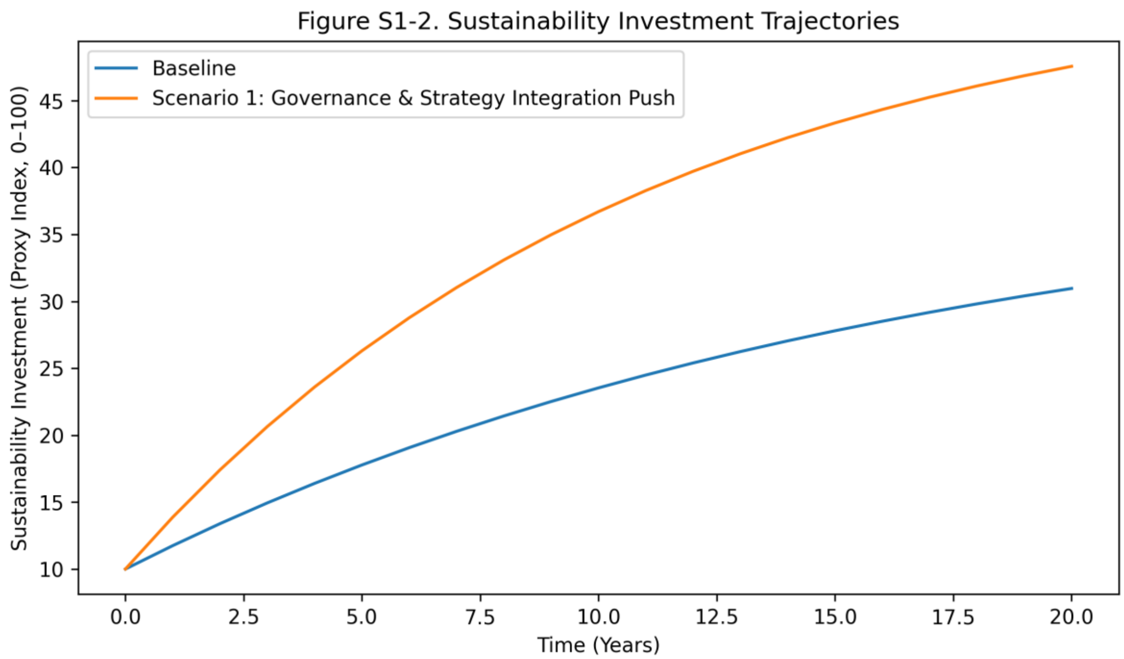

Figure S1-2: *Sustainability investment trajectories under baseline and governance integration scenarios. Governance integration increases the level and consistency of sustainability investment by strengthening the linkage between strategic commitment and resource allocation.* (source: SD model results)

Sustainability-oriented innovation and entrepreneurship improve under Scenario 1 but with noticeable delays. As shown in Figure S1-3, innovation trajectories rise above baseline conditions but remain below the levels achieved in Scenarios 2 and 4. The delayed response reflects the time required for strengthened governance and strategic alignment to translate into operational change and innovation outputs.

From a SD perspective, this pattern illustrates that governance integration activates reinforcing loops indirectly. Strategic commitment stabilizes investment, which gradually supports capability development and innovation, but the absence of explicit capability-building or ecosystem mechanisms limits the speed of innovation diffusion.

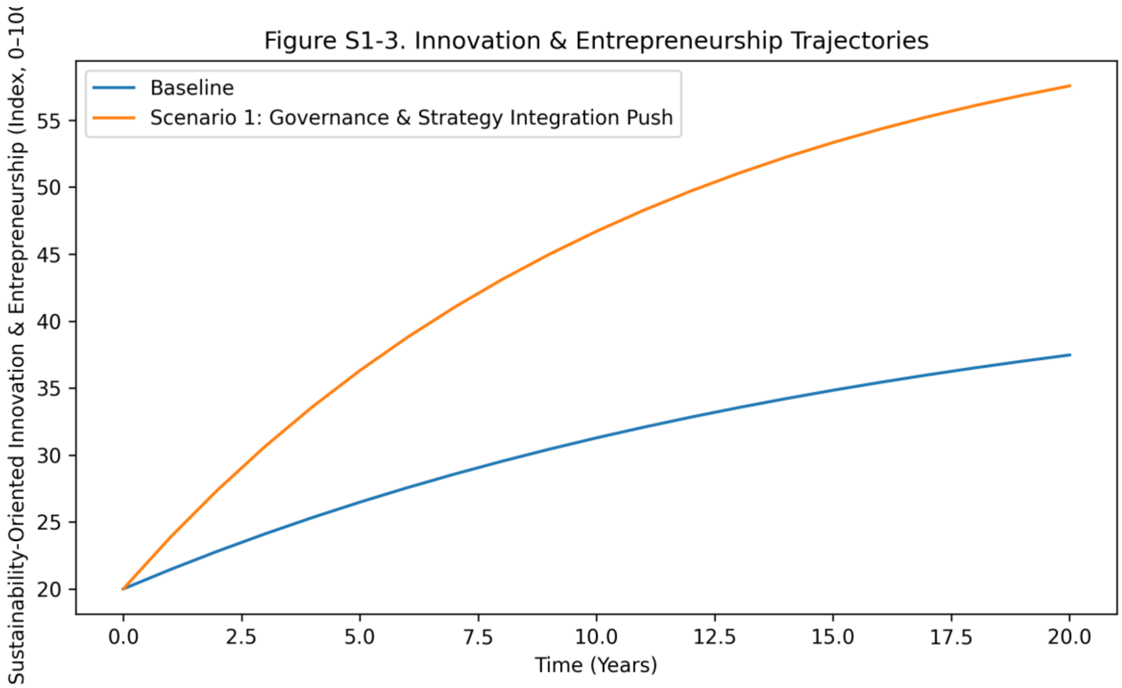

Figure S1-3: *Sustainability-oriented innovation and entrepreneurship trajectories under baseline and governance integration scenarios. Governance integration improves innovation performance gradually by stabilizing strategic commitment and investment, though with observable implementation delays.* (source: SD model results)

Institutional legitimacy and reputation improve steadily under Scenario 1, as shown in Figure S1-4. Legitimacy gains are driven by consistent, visible progress rather than rapid innovation breakthroughs. These gains feed back into strategic commitment, reinforcing governance support for sustainability over time.

Compared to Scenario 4, where legitimacy is driven primarily by innovation visibility, Scenario 1 demonstrates a more conservative but durable pathway to legitimacy. This finding underscores the complementary roles of governance and innovation in shaping reputational outcomes.As summarized in Table 5-1 (comparative outcomes), Scenario 1 produces substantial improvements over baseline conditions across strategic commitment, investment, innovation, and legitimacy, though it does not achieve the transformative performance levels observed in capability- or ecosystem-centered scenarios. However, its primary contribution lies in enhancing system stability and institutionalizing sustainability within core governance processes. When interpreted alongside the other policy scenarios, Scenario 1 emerges as a foundational intervention. Governance and strategy integration provide the structural stability necessary for other interventions, such as dynamic capability building (Scenario 2) and innovation ecosystem acceleration (Scenario 4), to achieve their full potential. Without such integration, sustainability gains are more vulnerable to erosion and volatility, particularly in competitive or high-turnover institutional contexts.

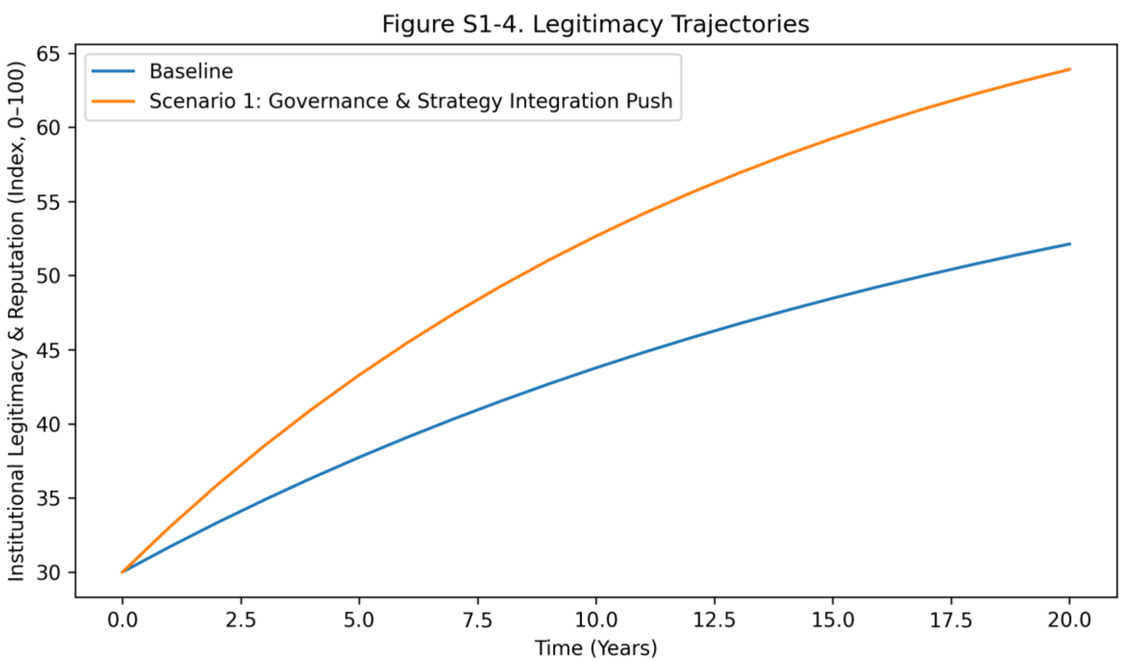

Figure S1-4: *Institutional legitimacy and reputation trajectories under baseline and governance integration scenarios. Governance integration supports steady legitimacy accumulation by reinforcing consistent sustainability outcomes over time.* (source: SD model results)

5.3.2 Policy Scenario 2 – Dynamic Capability Building

Policy Scenario 2 evaluates the effects of deliberately strengthening dynamic capabilities related to environmental sustainability, including organizational learning, cross-functional coordination, data-driven decision-making, and adaptive management. In this scenario, institutions invest in capability development through training, systems, and learning-by-doing mechanisms, while governance structures and cultural conditions remain broadly comparable to baseline conditions. The scenario tests whether capability accumulation alone can drive sustained sustainability transformation. Simulation results indicate that explicit investment in dynamic capability building produces a rapid and sustained increase in capability stocks relative to baseline conditions. As shown in Figure S2-1, dynamic capabilities accumulate faster and reach substantially higher long-run levels under Scenario 2. Reduced erosion and shortened learning delays further strengthen reinforcing feedback between investment, learning, and performance.

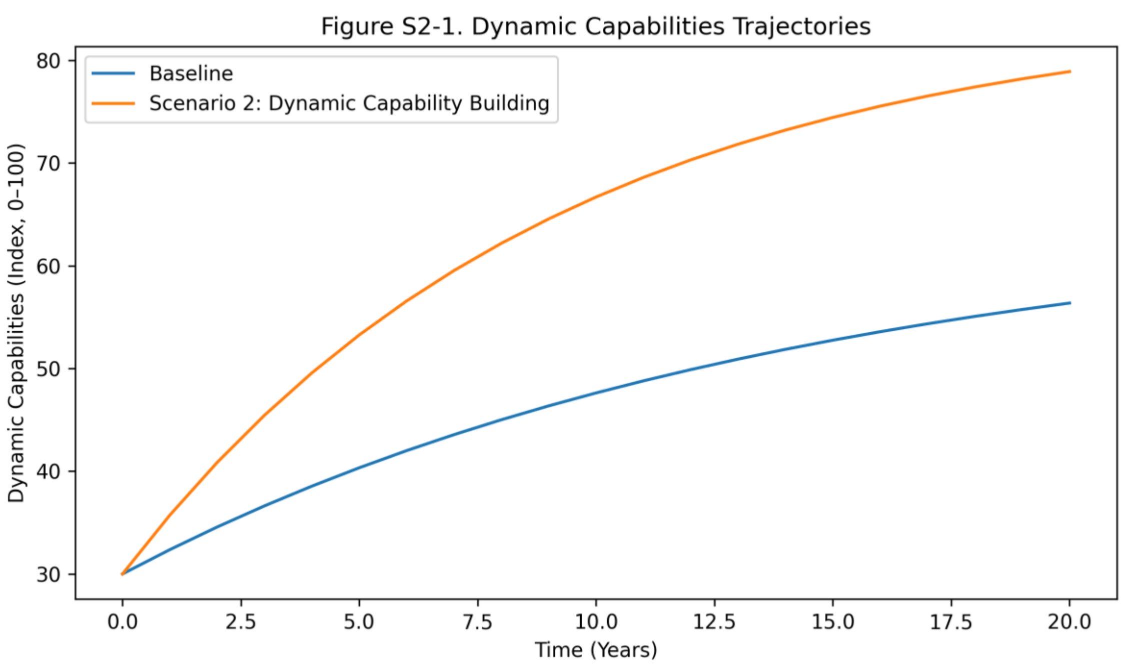

Figure S2-1: *Simulated trajectories of Dynamic Capabilities under baseline conditions and the Dynamic Capability Building intervention. The intervention accelerates capability accumulation and raises the long-run equilibrium, reflecting higher build rates and reduced erosion.* (source: SD model results)

Compared with Scenario 1, where strategic commitment stabilizes but capabilities grow gradually, Scenario 2 demonstrates that targeted capability interventions can quickly enhance an institution's ability to sense, seize, and reconfigure sustainability opportunities. However, the model also shows that capability growth is most effective when supported by sufficient investment and moderate resistance levels. The accumulation of dynamic capabilities translates into accelerated sustainability-oriented innovation and entrepreneurship. As illustrated in Figure S2-2, innovation trajectories rise earlier and more steeply than under baseline or governance-focused conditions. Capability-driven improvements in coordination, experimentation, and implementation reduce delays between strategic intent and innovation output.

Nevertheless, innovation growth under Scenario 2 remains somewhat constrained relative to Scenario 4, where ecosystem effects amplify innovation through external partnerships and visibility. This contrast suggests that while capabilities are essential enablers, they benefit from complementary mechanisms that scale and diffuse innovation beyond internal organizational boundaries. Improved innovation performance generates substantial gains in institutional legitimacy and reputation. As shown in Figure S2-3, legitimacy accumulates more rapidly and reaches higher long-run levels than in Scenarios 1 and 3. These legitimacy gains feed back into strategic commitment, reinforcing support for continued capability investment and creating a virtuous cycle of improvement.

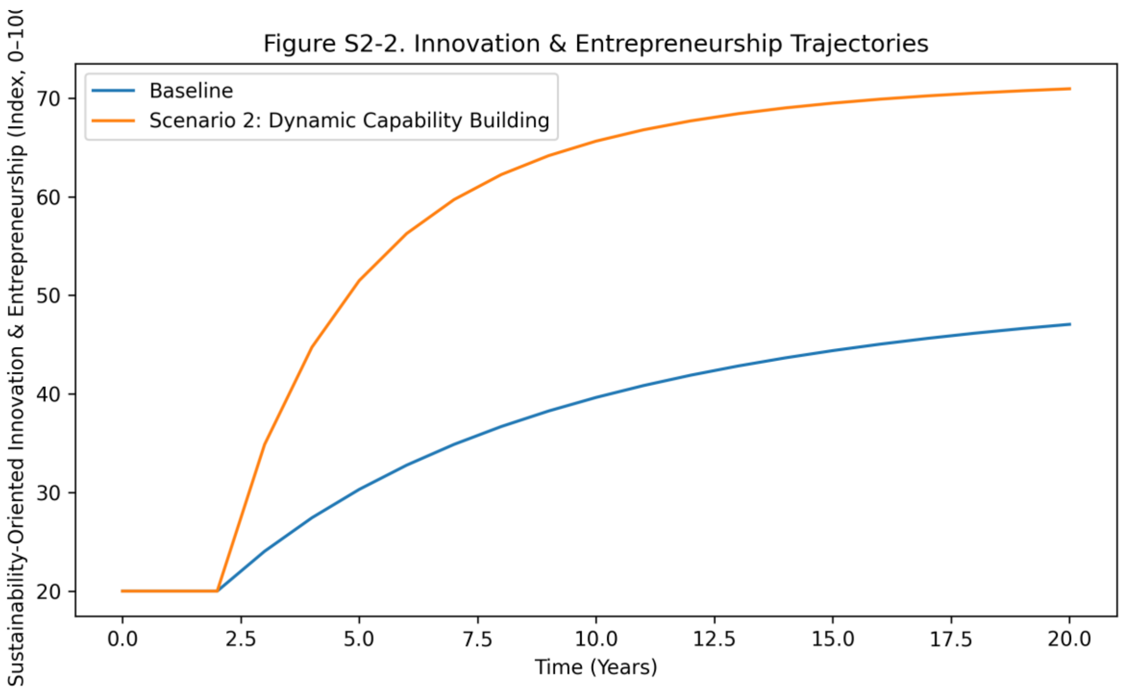

Figure S2-2: *Simulated trajectories of sustainability-oriented innovation and entrepreneurship under baseline conditions and the Dynamic Capability Building intervention. The scenario exhibits earlier and higher innovation growth, consistent with capability-driven implementation and reduced delays.* (source: SD model results)

However, the reinforcing loop between legitimacy and strategy remains partially contingent on governance structures. Without explicit governance integration, legitimacy gains may not fully translate into protected resources or long-term strategic anchoring, highlighting the complementarity between Scenario 2 and Scenario 1 interventions. As summarized in Table 5-1, Scenario 2 reaches critical performance thresholds, such as innovation and legitimacy indices exceeding 60, earlier than most other interventions. Dynamic capability building thus emerges as a powerful medium-term accelerator of sustainability performance, particularly in institutions with sufficient absorptive capacity and stable investment streams. However, the model also indicates diminishing returns to capability accumulation in the absence of broader ecosystem engagement. Once internal processes mature, additional gains depend increasingly on external collaboration, policy alignment, and innovation diffusion mechanisms.

When interpreted alongside the other policy scenarios, Scenario 2 occupies a central position in the sustainability transformation landscape. Dynamic capabilities act as a bridge between governance stability (Scenario 1), cultural alignment (Scenario 3), and innovation ecosystem acceleration (Scenario 4). Institutions that invest in capabilities without governance support may experience rapid early gains but face challenges in sustaining momentum, particularly in volatile contexts such as those modeled in Scenario 5. From a strategic perspective, the results suggest that dynamic capability building is most effective when combined with governance integration and cultural alignment. Capabilities enable action, but governance and culture determine whether that action is sustained and scaled.

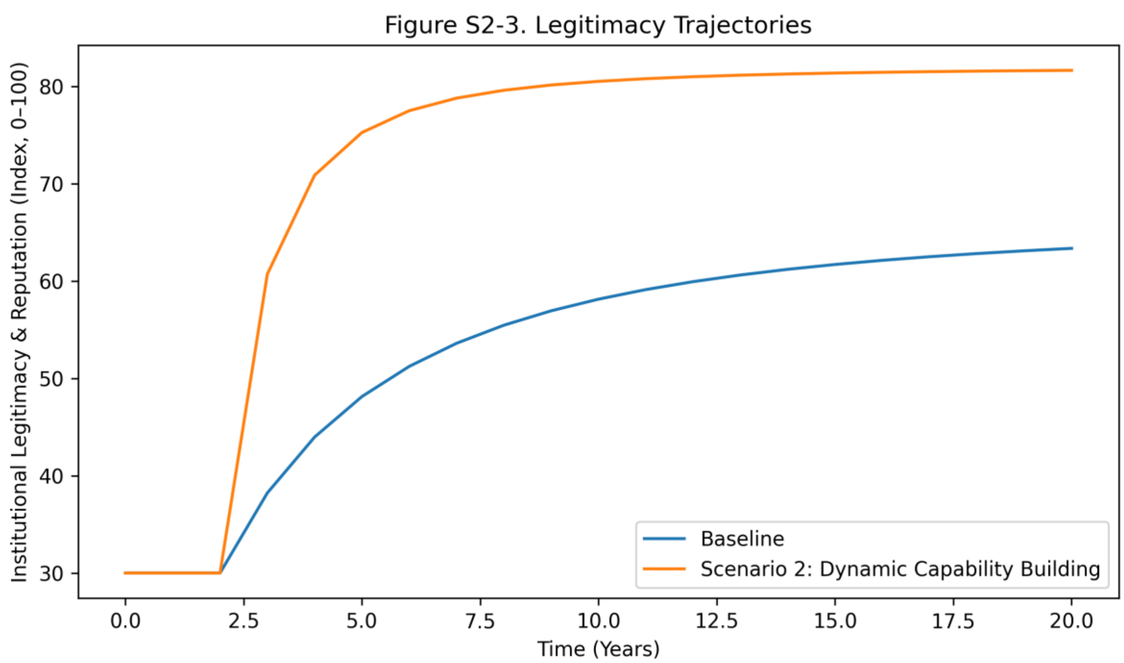

Figure S2-3: *Simulated trajectories of institutional legitimacy and reputation under baseline conditions and the Dynamic Capability Building intervention. Legitimacy rises more rapidly due to higher innovation output and stronger reinforcing feedback.* (source: SD model results)

5.3.3 Policy Scenario 3 – Organizational Change and Cultural Transformation

Policy Scenario 3 examines sustainability transformation driven primarily by organizational change and cultural alignment, rather than by governance restructuring (Scenario 1), intensive capability investment (Scenario 2), or innovation ecosystem expansion (Scenario 4). In this scenario, institutional leadership emphasizes participatory change processes, faculty and staff engagement, shared governance, and the normalization of sustainability values across academic and administrative units. Resource levels and formal strategic authority remain broadly comparable to baseline conditions. Relative to the baseline, Scenario 3 produces a marked acceleration in organizational alignment and a sustained reduction in resistance to sustainability initiatives. As shown in Figure S3-1, alignment accumulates more rapidly and stabilizes at a higher long-run level than under baseline conditions. This reflects the effectiveness of cultural interventions, such as dialog, sensemaking, and leadership signaling, in reducing fragmentation across decentralized institutional structures. When compared with Scenario 1, the alignment gains in Scenario 3 emerge earlier and more smoothly, but they lack the sharp inflection points associated with governance-driven reinforcement. Compared with Scenario 2, alignment improves independently of rapid capability accumulation, illustrating that cultural coherence can advance even when technical or managerial capabilities develop more slowly. These dynamics highlight culture's role in weakening balancing feedback associated with resistance, thereby stabilizing system behavior. Despite improvements in alignment, dynamic capability accumulation under Scenario 3 remains moderate. As illustrated indirectly through the innovation trajectories in Figure S3-2, capability development benefits from reduced resistance and improved collaboration, but grows more slowly than in Scenario 2, where explicit investments and learning mechanisms accelerate capability stocks.

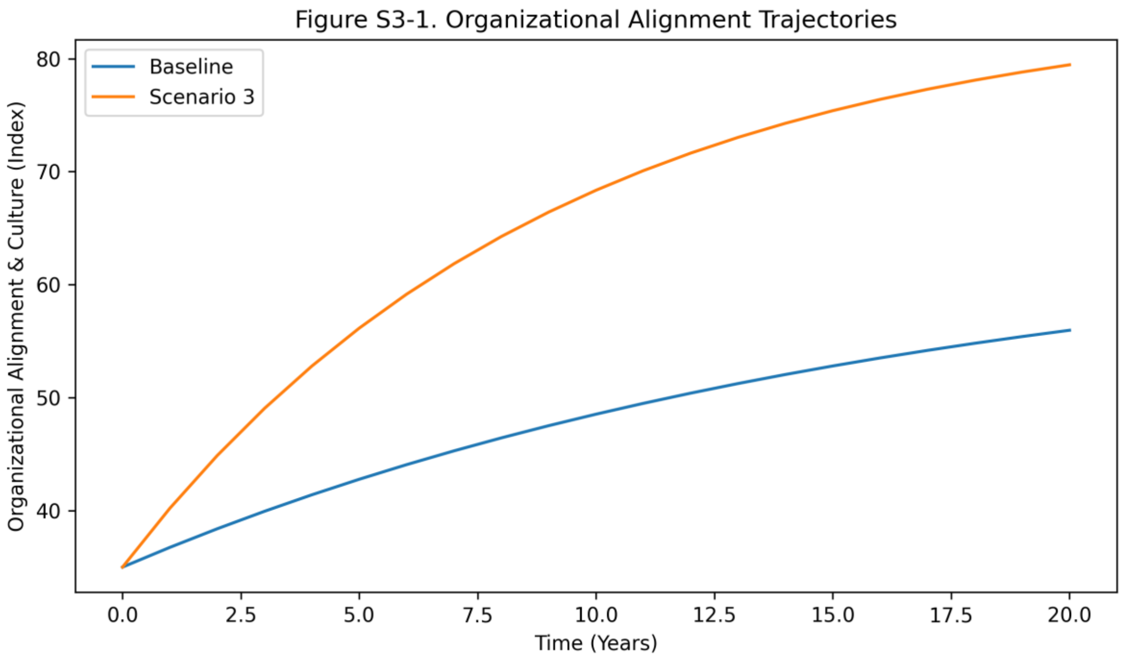

Figure S3-1: *Organizational alignment and culture trajectories under baseline and cultural transformation scenarios. Cultural transformation reduces organizational resistance and produces faster, more stable alignment than baseline conditions.* (source: SD model results)

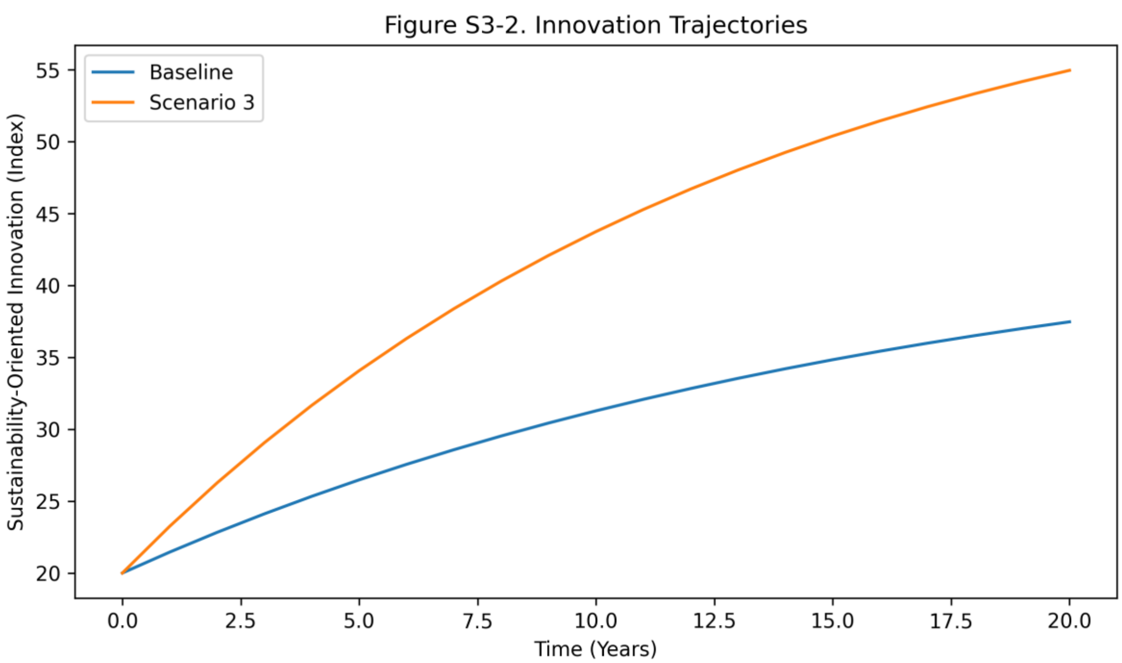

Figure S3-2: *Sustainability-oriented innovation and entrepreneurship trajectories under baseline and cultural transformation scenarios. Cultural alignment enables gradual innovation improvements, though growth remains constrained without complementary governance or ecosystem interventions.* . (source: SD model results)

This contrast underscores a key insight of the integrated results: cultural alignment is a necessary enabling condition for capability development but not a sufficient driver of rapid capability growth. In System Dynamics terms, Scenario 3 dampens resistance-related balancing loops but does not fully activate the reinforcing loops linking strategic commitment, investment, capabilities, and innovation that dominate Scenarios 1 and 2. Sustainability-oriented innovation and entrepreneurship improve steadily under Scenario 3, outperforming baseline trajectories but remaining below the levels achieved in Scenarios 2 and 4. As shown in Figure S3-2, innovation growth is gradual and delayed, reflecting the time required to translate cultural readiness into tangible outcomes in the absence of stronger strategic authority or resource reallocation.

Compared to Scenario 4, where innovation accelerates rapidly through ecosystem effects, Scenario 3 demonstrates a more incremental pattern of innovation diffusion. These results suggest that cultural alignment facilitates collaboration and experimentation but does not, on its own, generate the scale or speed of innovation required for transformative sustainability leadership. Institutional legitimacy and reputation increase modestly but steadily under Scenario 3, supported by visible though incremental sustainability achievements. While legitimacy gains are smaller than those observed in Scenarios 2 and 4, they are notably more stable over time. As summarized in Table 5-1, Scenario 3 achieves higher long-run legitimacy than baseline conditions, though it does not reach the threshold effects observed under capability- and ecosystem-driven interventions.

Importantly, Scenario 3 exhibits strong systemic stability. Cultural alignment buffers the system against leadership turnover and external shocks, a pattern that contrasts with the higher volatility observed in Scenario 5 under U.S.-like institutional conditions. This stabilizing effect highlights culture's critical role in sustaining progress even when performance gains are moderate.

Taken together, the results position Policy Scenario 3 as a foundational but insufficient strategy for sustainability transformation. Organizational change and cultural alignment reduce resistance, stabilize trajectories, and enable coherence across institutional units. However, without reinforcement from governance integration (Scenario 1), dynamic capability investment (Scenario 2), or innovation ecosystems (Scenario 4), cultural transformation alone does not generate the nonlinear performance gains required for rapid or large-scale sustainability advancement. From a strategic perspective, the integrated results suggest that cultural transformation is most effective when sequenced early or deployed in parallel with structural interventions. Culture enhances resilience and legitimacy, while governance and capability investments drive acceleration. This complementarity is particularly salient when interpreting Scenario 5, where contextual differences shape how cultural alignment interacts with institutional stability and external pressure.

5.3.4 Policy Scenario 4 – Sustainability Innovation Ecosystem Accelerator

Policy Scenario 4 examines the effects of deliberately accelerating sustainability transformation through the development of a comprehensive sustainability innovation ecosystem. In this scenario, higher education institutions invest in partnerships, incubators, living laboratories, external collaborations, and visibility mechanisms that link sustainability-oriented innovation and entrepreneurship to institutional strategy and external stakeholders. Unlike scenarios emphasizing governance reform (Scenario 1), capability accumulation (Scenario 2), or cultural alignment (Scenario 3), this intervention targets the amplification of innovation output and its translation into institutional legitimacy and strategic reinforcement. Simulation results indicate that Scenario 4 produces the most rapid and pronounced growth in sustainability-oriented innovation and entrepreneurship among all policy interventions. As illustrated in Figure S4-1, innovation trajectories accelerate sharply relative to baseline conditions and exceed the performance of governance- and capability-focused scenarios over the medium to long term. The presence of ecosystem mechanisms—such as cross-sector partnerships, applied research platforms, and innovation visibility—strengthens reinforcing feedback loops between innovation, investment, and legitimacy.

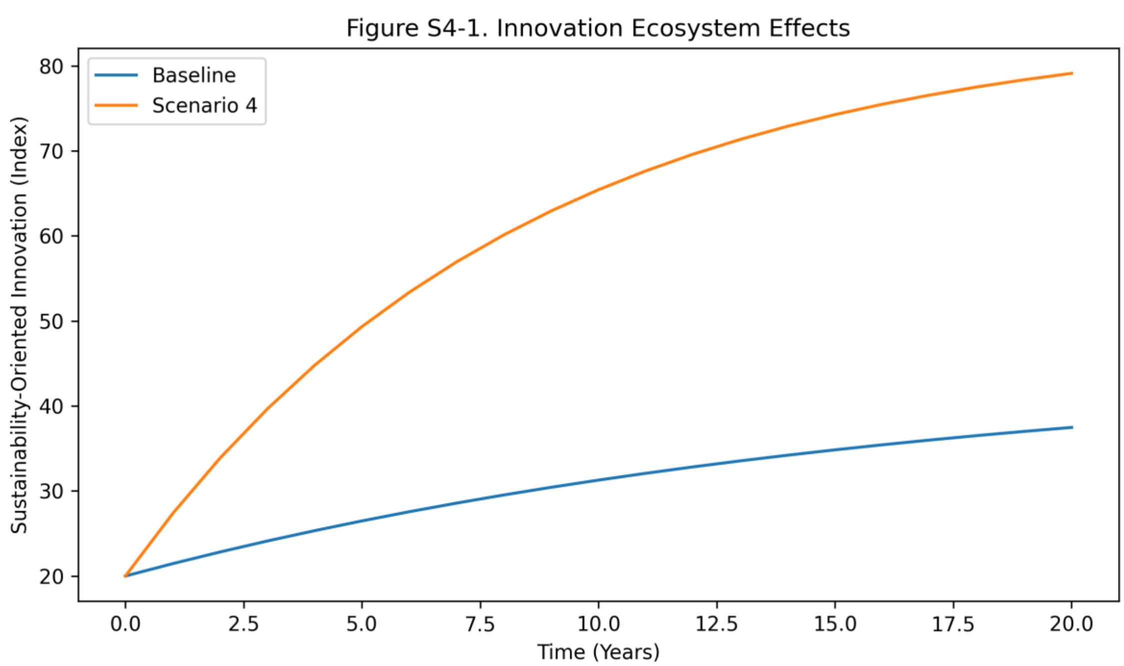

Figure S4-1: *Sustainability-oriented innovation and entrepreneurship trajectories under baseline and innovation ecosystem scenarios. Innovation ecosystem acceleration generates the fastest innovation growth by amplifying reinforcing feedback between innovation outcomes and institutional support.* (source: SD model results)

From a System Dynamics perspective, this scenario activates a powerful reinforcing loop in which innovation success attracts additional resources, partnerships, and attention, further enhancing innovation capacity. These dynamics contrast with the more incremental innovation growth observed in Scenario 3 (Figure S3-2), where cultural readiness exists but lacks ecosystem-level amplification. The rapid expansion of innovation under Scenario 4 translates directly into substantial gains in institutional legitimacy and reputation. As shown in Figure S4-2, legitimacy grows faster and reaches higher long-run levels than in any other scenario. This outcome reflects the visibility and signaling effects of ecosystem-based innovation, which strengthen external perceptions of leadership and credibility in sustainability. The legitimacy gains generated by Scenario 4 feed back into strategic commitment, reinforcing sustainability priorities at the executive and governing board levels. Compared with Scenario 1, where legitimacy strengthens strategy through governance channels, Scenario 4 demonstrates that innovation success itself can become a dominant driver of strategic reinforcement. This feedback loop enables the institution to sustain momentum even in the absence of formal governance restructuring.

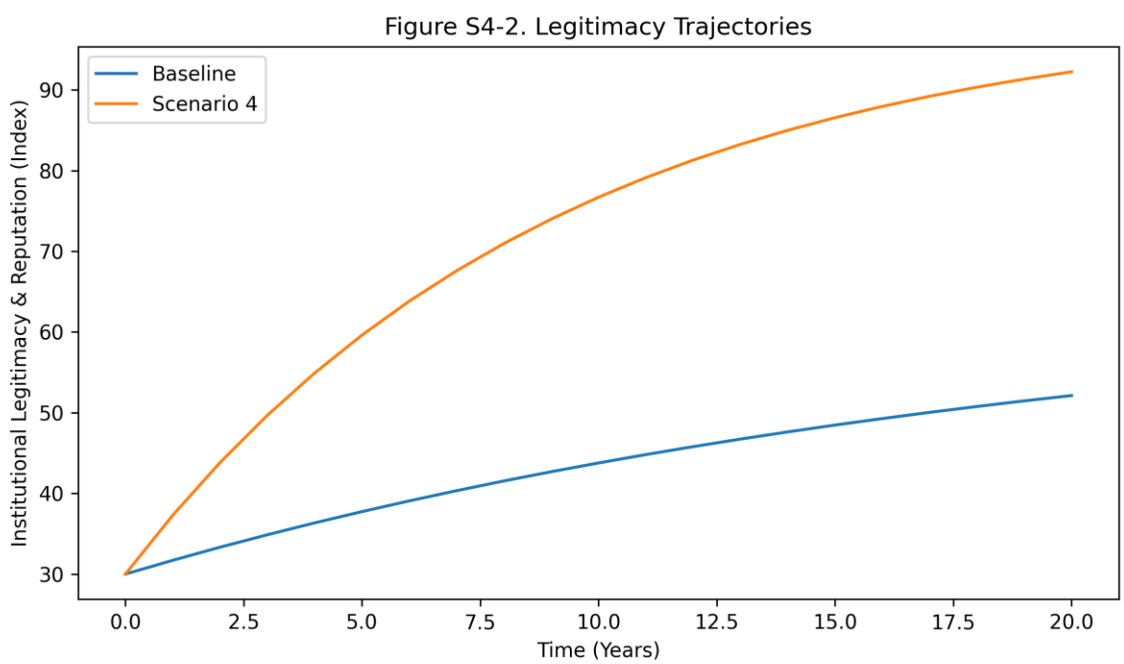

Figure S4-2: *Institutional legitimacy and reputation trajectories under baseline and innovation ecosystem scenarios. Innovation ecosystem development produces rapid and high-level legitimacy gains by amplifying the visibility of sustainability innovation outcomes.* (source: SD model results)

While Scenario 4 excels in innovation and legitimacy outcomes, the model reveals potential imbalances in capability and alignment development. Capability accumulation improves due to increased investment and learning-by-doing, but cultural alignment and organizational coherence may lag behind innovation growth if not deliberately addressed. This creates a risk of overextension, where innovation capacity outpaces internal absorptive capacity. This pattern contrasts with Scenario 2, where capability development is more balanced, but innovation grows more gradually. The comparison underscores a key insight of the integrated results: innovation ecosystems are powerful accelerators, but their effectiveness depends on the institution's underlying capability and cultural foundations.

As summarized in Table 5-1, Scenario 4 achieves the highest final levels of sustainability-oriented innovation and institutional legitimacy by the end of the simulation horizon. The model also indicates that Scenario 4 reaches critical innovation thresholds earlier than most other interventions, reinforcing its effectiveness as a rapid acceleration strategy. However, the long-term stability of these gains depends on complementary investments in governance, capabilities, and culture. Without such reinforcement, the system may become vulnerable to legitimacy loss or innovation fatigue, particularly under conditions of leadership turnover or resource constraints.

When interpreted alongside the other policy scenarios, Scenario 4 emerges as a high impact but potentially high-risk intervention. It delivers the strongest performance outcomes and positions institutions as visible sustainability leaders, but it relies on the presence—or subsequent development—of governance coherence (Scenario 1), dynamic capabilities (Scenario 2), and cultural alignment (Scenario 3) to remain sustainable over time. From a strategic perspective, the results suggest that innovation ecosystem acceleration is most effective when deployed after or alongside foundational interventions. Institutions that sequence cultural alignment and capability building before scaling innovation ecosystems are likely to achieve both rapid gains and long-term resilience.

5.3.5 Policy Scenario 5 – U.S. vs. International Institutional Contexts

Policy Scenario 5 examines how national and institutional context conditions the effectiveness of sustainability strategies in higher education institutions. Rather than introducing a new policy lever, this scenario compares the dynamic behavior of the system under two contextual regimes: a U.S.-like context characterized by higher leadership turnover, greater competition, and more market-driven incentives, and an international public-sector–oriented context characterized by greater institutional stability, stronger regulatory pressure, and longer planning horizons. The scenario addresses whether similar sustainability interventions generate different outcomes depending on institutional context. Simulation results indicate that institutional context significantly shapes both the pace and stability of sustainability-oriented innovation. As shown in Figure S5-1, U.S.-like institutions exhibit faster early innovation growth compared to international counterparts. Stronger competitive pressures and higher responsiveness to legitimacy signals accelerate initial investment in sustainability innovation and entrepreneurship. However, this early advantage is accompanied by greater volatility. Innovation trajectories in the U.S. context display sharper fluctuations over time, reflecting sensitivity to leadership turnover, shifting priorities, and resource reallocation. In contrast, international institutions show slower initial growth but more stable and persistent innovation accumulation. These institutions benefit from longer-term policy continuity and more consistent external pressure, which dampen oscillations and reduce the risk of regression. Differences in leadership stability and governance continuity translate into distinct patterns of strategic commitment and dynamic capability development. In the U.S. context, strategic commitment responds rapidly to changes in legitimacy and external pressure but also decays more quickly following leadership transitions. This pattern weakens the reinforcing feedback between commitment, investment, and capability accumulation.

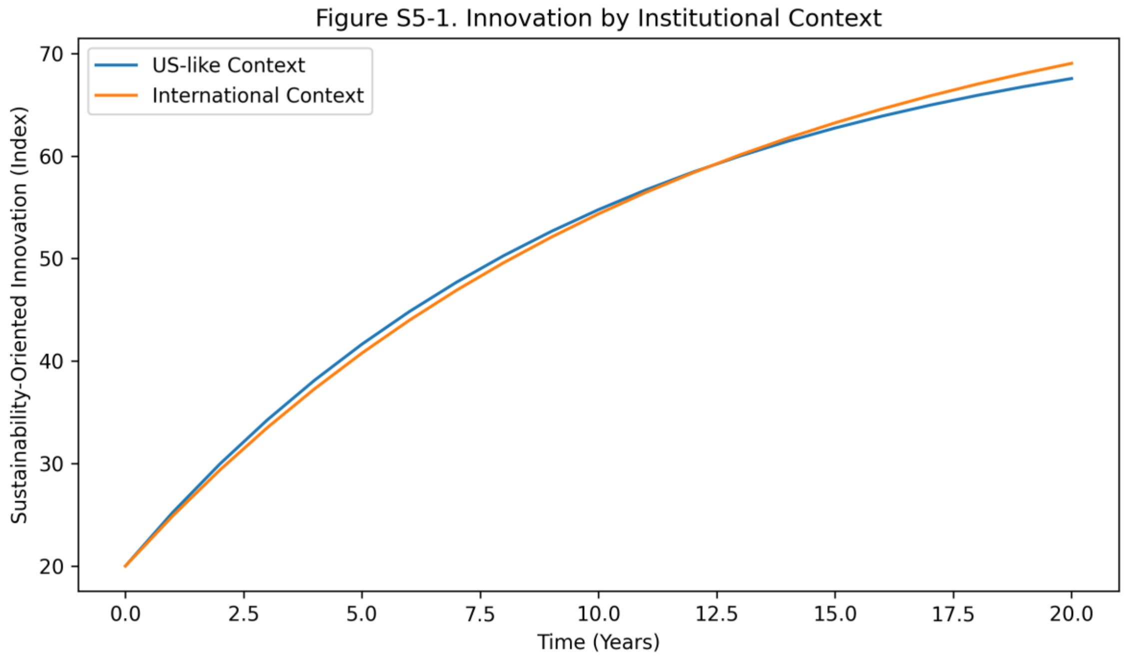

Figure S5-1: *Sustainability-oriented innovation trajectories under U.S. and international institutional contexts. Institutional context shapes both the speed and stability of innovation, with U.S. contexts favoring rapid but volatile growth and international contexts favoring steady accumulation.* (source: SD model results)

By contrast, international institutions maintain more stable strategic commitment over time, supporting steadier capability development even when innovation growth is slower. This finding aligns with results from Scenarios 1 and 2, which emphasize the importance of governance stability and long-term investment for sustaining dynamic capabilities. Scenario 5 thus demonstrates that context can either amplify or constrain the effectiveness of otherwise similar strategies.

Institutional legitimacy evolves differently across contexts due to variations in visibility mechanisms and stakeholder expectations. In U.S.-like institutions, legitimacy gains are more tightly coupled to visible innovation outputs and rankings performance, producing rapid feedback into strategic commitment. However, legitimacy losses can also occur more abruptly when performance stagnates or leadership priorities shift. International institutions experience more gradual legitimacy accumulation, often driven by regulatory compliance, public accountability, and alignment with national sustainability agendas. While this reduces the speed of legitimacy gains, it enhances durability and lowers the risk of reputational decline. As summarized in Table 5-1, international contexts achieve comparable long-term legitimacy levels with greater stability, despite slower initial progress.

When integrated with the results of Scenarios 1–4, Scenario 5 highlights the context-dependence of sustainability transformation pathways. Governance integration (Scenario 1) and capability building (Scenario 2) are particularly critical in U.S. contexts to offset volatility and leadership turnover. Conversely, innovation ecosystem strategies (Scenario 4) perform especially well in international contexts when embedded within stable governance and policy frameworks. Cultural alignment strategies (Scenario 3) emerge as universally beneficial but contextually differentiated: they enhance resilience in U.S. institutions and accelerate coherence in international ones. Overall, Scenario 5 demonstrates that no single sustainability strategy is universally optimal; effectiveness depends on how interventions interact with institutional context and national governance regimes.

The results suggest that sustainability strategies in higher education must be context-sensitive rather than uniform. U.S. institutions may require stronger institutionalization mechanisms, such as formal governance integration and protected sustainability budgets, to counteract volatility. International institutions, while benefiting from stability, may need targeted innovation incentives to accelerate early-stage progress. From a SD perspective, Scenario 5 underscores that institutional context shapes the strength and timing of reinforcing and balancing feedback loops. Ignoring these contextual differences risks misinterpreting performance outcomes or misapplying best practices across institutional settings.

5.4 Integrative Synthesis: What the Policy Scenarios Collectively Reveal

The five policy scenarios reveal that sustainability transformation in higher education institutions is driven not by isolated interventions, but by the interaction of multiple reinforcing and balancing feedback processes. The SD simulations demonstrate that no single policy lever, whether governance reform, capability investment, cultural change, or innovation ecosystem development, is sufficient on its own to produce sustained, transformative outcomes. Instead, performance depends on how these levers activate, complement, or constrain one another over time. Governance and strategy integration emerge as foundational stabilizers. By reducing strategic decay and buffering leadership turnover, governance reforms create the conditions under which other interventions can persist. However, governance alone produces gradual change and limited acceleration unless paired with mechanisms that enhance execution capacity and innovation. Dynamic capability building functions as a central accelerator. Capabilities enable institutions to translate strategic intent into action, shorten implementation delays, and reach performance thresholds earlier than under baseline conditions. Yet, capability accumulation exhibits diminishing returns when not reinforced by governance anchoring or scaled through innovation ecosystems.

Organizational change and cultural transformation play a critical enabling and buffering role. Cultural alignment reduces resistance, smooths trajectories, and enhances system resilience, particularly under volatile conditions. However, cultural change alone does not generate rapid performance gains, underscoring its role as a necessary but insufficient driver of transformation. Innovation ecosystem acceleration delivers the highest performance outcomes but also introduces the greatest risk of imbalance. Ecosystem strategies amplify reinforcing loops between innovation and legitimacy, enabling rapid leadership positioning. These benefits are sustainable only when supported by strong governance, capabilities, and cultural coherence. Finally, institutional context fundamentally shapes system behavior. U.S.-like contexts favor speed and responsiveness but exhibit higher volatility, while international contexts favor stability and durability at the cost of slower early progress. Effective sustainability strategies must therefore be context-sensitive and adaptive.

Collectively, the scenarios reveal that successful sustainability transformation requires a portfolio approach, combining stabilizing, enabling, and accelerating interventions in a sequence aligned with institutional context. This insight reinforces the value of System Dynamics as a lens for understanding sustainability as a long-term organizational transformation rather than a collection of discrete initiatives. Table 5-1 synthesizes the dynamic performance of the five policy scenarios, highlighting complementarities and trade-offs. The results demonstrate that no single intervention is sufficient for sustained sustainability transformation; rather, effective strategies combine governance stability, capability development, cultural alignment, and innovation amplification in context-sensitive ways. Governance and cultural interventions enhance system stability, while capability and ecosystem strategies drive acceleration. Context conditions determine which combinations are most effective and which risks must be managed.

Table 5-1: Cross-Scenario Synthesis: Complementarities and Trade-offs across Sustainability Policy Interventions (source: prepared for this research).

Policy Scenario	Primary Leverage Mechanism	Key Strengths	Key Trade-offs / Risks	Best Used When	Complementary Scenarios
Baseline (No Policy Push)	Incremental learning under external pressure	Low cost; minimal disruption	Slow progress; vulnerable to regression; rarely reaches transformative thresholds	Benchmarking and diagnostics	All (serves as counterfactual)
Scenario 1: Governance & Strategy Integration Push	Formal authority, strategic anchoring, reduced decay	High stability; durable commitment; protects sustainability priorities	Slower innovation uptake; limited acceleration without additional investments	Institutions with leadership turnover or fragmented governance	Scenarios 2, 3, and 4

Policy Scenario	Primary Leverage Mechanism	Key Strengths	Key Trade-offs / Risks	Best Used When	Complementary Scenarios
Scenario 2: Dynamic Capability Building	Learning, coordination, adaptive capacity	Rapid medium-term gains; early threshold attainment; strong innovation enablement	Diminishing returns without governance or ecosystem support; resource-intensive	Institutions ready to scale action but lacking execution capacity	Scenarios 1 and 4
Scenario 3: Organizational Change & Cultural Transformation	Reduced resistance; shared values; coherence	High resilience; smooth trajectories; buffers shocks	Limited acceleration; insufficient alone for transformative outcomes	Early-stage transformation; change fatigue environments	Scenarios 1 and 2
Scenario 4: Sustainability Innovation Ecosystem Accelerator	Reinforcing innovation–legitimacy loops	Highest performance; fastest innovation growth; strong	Risk of overextension; requires strong internal	Institutions seeking leadership positioning	Scenarios 1, 2, and 3

Policy Scenario	Primary Leverage Mechanism	Key Strengths	Key Trade-offs / Risks	Best Used When	Complementary Scenarios
		external visibility	capacity and alignment		
Scenario 5: U.S. Context	Competitive pressure; legitimacy signaling	Fast early gains; strong responsiveness	High volatility; leadership dependence	Market-driven or decentralized systems	Scenarios 1 and 3
Scenario 5: International Context	Policy stability; regulatory pressure	Long-term consistency; lower risk of regression	Slower early progress; less innovation dynamism	Public or policy-coordinated systems	Scenarios 2 and 4

Taken together, the scenarios reveal several overarching patterns. First, sustainability transformation in HEROs is driven by reinforcing feedback loops, particularly those linking strategy, capabilities, innovation, and legitimacy. Second, governance and culture function as structural enablers, shaping whether investments in capabilities and innovation yield durable returns. Third, delays and nonlinearities mean that effective policies often appear ineffective in the short term, creating a risk of premature abandonment. The results contribute to theory by integrating dynamic capabilities, organizational change, and sustainability transitions into a unified, dynamic explanation of institutional transformation. The findings extend the dynamic capabilities framework by explicitly modeling how capabilities interact with governance, culture, and legitimacy over time, rather than treating them as static attributes.

For university leaders, the results suggest that sustainability success depends less on isolated initiatives and more on sequencing and alignment. Governance integration should precede or accompany capability and innovation investments. Change management should be treated as a continuous process rather than a one-time intervention. Innovation ecosystems should be embedded within institutional strategy to avoid volatility and legitimacy risk. For policymakers and sustainability networks, the findings highlight the value of incentives that promote institutionalization rather than project proliferation. Ranking systems and reporting frameworks such as STARS can play a constructive role by reinforcing legitimacy feedback, provided they are interpreted as learning tools rather than compliance checklists.

These results demonstrate how System Dynamics modeling can illuminate the complex, long-term dynamics of sustainability transformation in higher education. By integrating empirical data, organizational theory, and policy experimentation, the analysis reveals why some institutions achieve sustainability leadership while others stagnate despite similar aspirations. The results affirm the central premise of this dissertation: environmental sustainability in higher education is fundamentally an organizational capability challenge, shaped by feedback, context, and strategic design over time.

CHAPTER 6

CASE STUDY APPLICATION – UNIVERSITY SYSTEM OF MARYLAND

6.1 Overview

This chapter applies the System Dynamics framework developed in this dissertation to a real-world institutional context through an in-depth case study of the University System of Maryland (USM). The purpose of the chapter is to demonstrate how the conceptual model, policy scenarios, and dynamic insights generated by the research can inform strategic decision-making in a complex, multi-institutional higher education system. By grounding the model in the governance structures, strategic priorities, and sustainability ambitions of USM, the chapter bridges theory and practice and illustrates the practical relevance of the research.

USM provides a particularly suitable case study due to its scale, diversity of institutional missions, and system-level governance structure, which together create both opportunities and challenges for coordinated sustainability transformation. The chapter uses USM as an illustrative application rather than a strict validation exercise, focusing on how the System Dynamics model can be calibrated, interpreted, and used as a strategic learning tool by system leaders. Emphasis is placed on translating model insights into actionable policy levers, sequencing strategies across institutions, and identifying trade-offs between stability, innovation, and equity in sustainability implementation. The chapter is structured to first situate USM within the broader context of sustainability in public higher education systems, then map system characteristics onto the model structure and policy scenarios developed in earlier chapters. It concludes by discussing how a system-level application enhances understanding of sustainability as a dynamic, long-term organizational transformation process.

6.2 University System of Maryland: System Context and Governance

The University System of Maryland (USM) is one of the largest and most complex public higher education systems in the United States, comprising multiple constituent institutions with diverse missions, scales, and stakeholder environments. These include research-intensive flagship campuses, comprehensive universities, and regional institutions serving distinct educational, economic, and social roles within the State of Maryland. This diversity creates both opportunities for system-level sustainability leadership and structural challenges for coordinated implementation.

USM operates under a centralized governance framework led by a Board of Regents, with system-level offices responsible for strategic planning, policy coordination, financial oversight, and accountability to state government. At the same time, significant operational authority resides at the campus level, particularly with respect to academic priorities, facilities management, and day-to-day sustainability initiatives. This hybrid governance structure—combining centralized strategic authority with decentralized execution—is characteristic of many U.S. public university systems and is a critical contextual feature for understanding sustainability transformation dynamics.

From a sustainability perspective, USM has articulated system-wide commitments related to environmental stewardship, climate action, operational efficiency, and social responsibility, often aligned with state-level policy goals and public accountability requirements. However, implementation capacity varies across campuses due to differences in resources, leadership priorities, institutional culture, and technical expertise. As a result, sustainability performance within the system exhibits uneven trajectories, with some institutions acting as early adopters and innovators while others progress more incrementally.

This governance and contextual configuration make USM particularly well suited for a SD–based application. The system exhibits strong reinforcing and balancing feedbacks between system-level strategy, campus autonomy, resource allocation, innovation diffusion, and legitimacy with external stakeholders. Decisions made at the system level—such as strategic mandates, performance metrics, or shared investment mechanisms—interact dynamically with campus-level capabilities and cultures, producing non-linear and time-delayed outcomes. Understanding these interactions is essential for designing sustainability strategies that balance stability, flexibility, and innovation across the system.

In this chapter, USM is treated not as a single homogeneous organization, but as a multi-level system in which governance, context, and institutional diversity shape sustainability trajectories. This framing allows the System Dynamics model developed in earlier chapters to be interpreted as a strategic learning tool for system leaders, illuminating how different policy levers may perform under realistic governance constraints and contextual conditions.

6.3 Mapping of USM to Policy Scenarios

The sustainability strategy of the USM reflects a multi-level and evolving approach shaped by system-wide commitments, state policy priorities, and campus-level initiative. Rather than a single unified program, USM's sustainability efforts comprise a portfolio of governance actions, capability investments, cultural initiatives, and innovation activities that align closely with the five policy scenarios examined in this dissertation. Mapping existing and emerging USM practices onto these scenarios provides a structured way to interpret both current progress and future strategic options.

Scenario 1: Governance and Strategy Integration Push

At the system level, USM exhibits several elements consistent with governance and strategy integration. Sustainability-related priorities are embedded in system planning, capital investment decisions, and reporting requirements, often aligned with Maryland's climate and energy policies. The Board of Regents and system office play a coordinating role by setting expectations, facilitating compliance, and encouraging alignment across institutions. However, the degree of formalization varies, and sustainability is not uniformly embedded as a core performance criterion across all governance and budgeting processes. This places USM in a partial implementation of Scenario 1, where strategic commitment is present but not yet fully institutionalized across all decision domains.

Scenario 2: Dynamic Capability Building

USM campuses have invested unevenly in sustainability-related capabilities, including energy management systems, data tracking and reporting, professional staff expertise, and cross-functional coordination mechanisms. Some institutions demonstrate advanced capabilities in monitoring, analytics, and adaptive management, while others rely on ad hoc or project-based approaches. At the system level, opportunities exist to strengthen shared services, common data platforms, and peer learning networks, which would more fully activate Scenario 2 dynamics by accelerating learning and reducing duplication of effort.

Scenario 3: Organizational Change and Cultural Transformation

Cultural alignment around sustainability within USM is largely driven at the campus level through faculty engagement, student initiatives, operational leadership, and community partnerships. While sustainability values are widely endorsed, their integration into everyday decision-making varies substantially across institutions. System-wide communication and engagement efforts have helped normalize sustainability as a shared aspiration, but resistance and competing priorities persist in some units. These conditions align closely with Scenario 3, where cultural change supports progress and resilience but does not, on its own, guarantee rapid or uniform advancement.

Scenario 4: Sustainability Innovation Ecosystem Accelerator

Several USM institutions participate in sustainability-oriented research, innovation, and entrepreneurship activities, including applied research centers, public–private partnerships, and community-facing initiatives. These efforts generate visibility and external legitimacy, particularly at flagship and research-intensive campuses. However, ecosystem activities are not fully coordinated at the system level, limiting opportunities for scale, diffusion, and shared learning. From a System Dynamics perspective, USM demonstrates localized instances of Scenario 4 without yet realizing its full system-wide reinforcing potential.

Scenario 5: Institutional Context (U.S. Public Higher Education)

USM operates squarely within a U.S.-like institutional context characterized by shared governance, leadership turnover, competitive pressures, and accountability to public stakeholders. These conditions amplify both opportunities for rapid innovation and risks of strategic volatility.

As shown in the model's Scenario 5 results, this context increases the importance of governance integration and cultural alignment to stabilize progress, while also making ecosystem and capability investments particularly valuable when properly anchored. Taken together, this mapping suggests that USM already embodies elements of all five policy scenarios, but in a fragmented and uneven manner. The System Dynamics framework developed in this dissertation offers a structured way to assess how stronger integration, sequencing, and coordination across these strategic dimensions could enhance system-wide sustainability outcomes while respecting institutional diversity and autonomy.

Table 6-1 shows observed sustainability practices within the University System of Maryland in the context of the policy scenarios developed in this dissertation. The analysis highlights areas of alignment, partial implementation, and opportunity for strategic reinforcement. This comparison indicates that the USM already exhibits meaningful alignment with each of the policy scenario archetypes, but rarely in a fully integrated or system-wide manner. Current practices reflect a hybrid configuration in which governance commitment, capabilities, culture, and innovation coexist unevenly across campuses. The most significant gaps lie not in the absence of sustainability ambition, but in the coordination, sequencing, and institutionalization of existing efforts. These gaps suggest that future progress depends less on introducing entirely new initiatives and more on strategically aligning and reinforcing those already underway.

Table 6-1: Gap Analysis: Current USM Practices versus Policy Scenario Archetypes
(Case study: University System of Maryland) (source: prepared for this research)

Policy Scenario	**Scenario Archetype (Model Ideal)**	**Current USM Practices (Observed Pattern)**	**Key Gaps Identified**	**Strategic Implications**
Scenario 1: Governance & Strategy Integration	Sustainability fully embedded in system governance, budgeting, performance management, and accountability mechanisms; minimal strategic decay	Sustainability articulated in system plans and aligned with state policy; uneven integration into budgeting and performance metrics; campus-level discretion remains high	Partial institutionalization; limited use of sustainability as a binding decision criterion	Strengthening formal governance integration could stabilize long-term commitment and protect sustainability priorities across leadership cycles
Scenario 2: Dynamic Capability Building	Strong, system-wide capabilities for data, analytics, learning, coordination, and	Capabilities vary widely across campuses; strong pockets of expertise but limited system-	Fragmented learning; duplication of effort; slower diffusion of best practices	Coordinated capability investments could accelerate performance while respecting

Policy Scenario	Scenario Archetype (Model Ideal)	Current USM Practices (Observed Pattern)	Key Gaps Identified	Strategic Implications
	adaptive management; shared platforms and routines	level standardization or shared services		campus autonomy
Scenario 3: Organizational Change & Culture	High cultural alignment; low resistance; sustainability embedded in everyday decision-making across units	Broad rhetorical support for sustainability; uneven internalization; pockets of resistance due to competing priorities	Cultural alignment not consistently translated into action	Targeted change management could reduce friction and enhance resilience, especially during transitions
Scenario 4: Innovation Ecosystem Accelerator	Integrated system-level sustainability innovation ecosystem;	Innovation concentrated at select campuses; limited system-wide coordination	Ecosystem benefits localized rather than system-wide	System-level coordination could amplify innovation

Policy Scenario	Scenario Archetype (Model Ideal)	Current USM Practices (Observed Pattern)	Key Gaps Identified	Strategic Implications
	strong external partnerships; rapid diffusion and visibility	or scaling mechanisms		outcomes and legitimacy
Scenario 5: Institutional Context (U.S.)	Context-aware strategies that mitigate volatility and leverage competition	High responsiveness and innovation potential; exposure to leadership turnover and funding uncertainty	Elevated risk of strategic volatility	Governance anchoring and cultural coherence are especially critical in the USM context

This gap analysis can now be used to explore how selected policy scenarios could be operationalized within the USM context.

6.4 USM-Specific Scenario Walkthrough Using the SD Model

This section illustrates how the System Dynamics (SD) model developed in Chapters 4 and 5 can be applied as a decision-support and strategic learning tool for the University System of Maryland

(USM). Rather than treating USM as a single homogeneous institution, the walkthrough interprets USM as a multi-campus system in which governance authority is partially centralized, implementation capacity varies across campuses, and sustainability outcomes emerge from the interaction of system-level strategy with campus-level execution. The walkthrough proceeds by (1) establishing a plausible "USM baseline" starting condition consistent with the gap analysis, (2) translating each policy scenario into USM-relevant interventions, and (3) identifying expected dynamic behaviors, sequencing logic, and decision trade-offs.

6.4.1 Establishing a USM Baseline for Model Use

To use the SD model for USM, the baseline should represent USM's current hybrid state: system-level strategic commitment exists but is not fully institutionalized in performance and budgeting; sustainability capabilities are strong at some campuses but uneven system-wide; cultural alignment is broadly positive but inconsistent across units; and innovation ecosystem activity is present but not coordinated at scale. In SD terms, this implies moderate initial values for strategic commitment and legitimacy, heterogeneous (but average moderate) capability stocks, and a meaningful but non-negligible resistance level reflecting decentralized governance, competing priorities, and uneven absorptive capacity. The model can represent heterogeneity by running (a) a "system-average" baseline and (b) additional sensitivity runs for campus archetypes (e.g., flagship research campus, comprehensive institution, regional campus), then comparing patterns rather than focusing on a single point estimate.

6.4.2 Scenario 1 in the USM Context: Governance and Strategy Integration Push

In the USM context, Scenario 1 corresponds to strengthening formal system-wide sustainability governance: clearer Board of Regents oversight, tighter linkage between sustainability goals and capital planning, system-level sustainability performance indicators used in budgeting, and standardized reporting requirements. In the model, these actions increase the rate at which strategic commitment is reinforced and reduce commitment decay. For USM, the primary expected effect is stabilization: system-wide strategic commitment becomes less sensitive to leadership transitions and campus-to-campus variability. The walkthrough interpretation is that Scenario 1 functions as a "platform intervention" for USM, creating consistent expectations and protecting sustainability priorities long enough for capabilities and innovation to mature. A governance push is therefore most valuable early in the transformation sequence, particularly given the U.S.-like volatility regime highlighted in Scenario 5.

6.4.3 Scenario 2 in the USM Context: Dynamic Capability Building

Scenario 2 translates for USM into system-coordinated capability building that reduces duplication and accelerates diffusion of best practices. Examples include shared data infrastructure for energy and emissions tracking; a system-wide sustainability analytics function; cross-campus training programs; communities of practice; and shared implementation playbooks for procurement, facilities, and reporting. In the model, these actions raise the capability development rate, reduce capability erosion, and shorten delays between learning and innovation outcomes. For USM, the expected dynamic behavior is faster conversion of intent into outcomes: once governance stabilizes commitment, capability building accelerates implementation across campuses, particularly those with historically limited capacity. The SD logic suggests a leverage point in reducing delays—USM can often improve system performance not by increasing ambition, but by improving speed and consistency of execution across institutions.

6.4.4 Scenario 3 in the USM Context: Organizational Change and Cultural Transformation

Scenario 3 aligns with USM strategies that build culture and reduce resistance: faculty engagement on curriculum and research, staff empowerment in operations, student co-creation, and shared narratives linking sustainability to mission (e.g., student success, public service, research excellence). In the model, this reduces resistance and increases the rate of alignment accumulation. For USM, this scenario is especially relevant because system-level mandates alone can trigger pushback in decentralized academic environments. The SD walkthrough indicates that cultural alignment is a stabilizer and multiplier: it smooths implementation, reduces friction in cross-campus coordination, and buffers the system against oscillations caused by leadership turnover or shifting priorities. In sequencing terms, cultural work is not a “nice to have”; it is the mechanism that makes governance and capability interventions politically and operationally durable.

6.4.5 Scenario 4 in the USM Context: Sustainability Innovation Ecosystem Accelerator

Scenario 4 corresponds to scaling USM’s sustainability innovation ecosystem beyond isolated campus pockets. In practice, this could include a system-wide sustainability innovation network connecting incubators, research centers, and community partners; shared challenge funds; living laboratory programs across campuses; and coordinated external partnership development. In the model, this increases innovation productivity and strengthens the legitimacy amplification effects of visible sustainability success. For USM, the expected dynamic behavior is rapid growth in sustainability innovation outcomes and reputational gains—particularly when innovations are public-facing and tied to workforce development, industry collaboration, and state priorities. The SD lens also reveals the primary risk: innovation ecosystems can outpace internal absorptive capacity if capabilities and alignment are weak, leading to fatigue or uneven benefits. Therefore, in the USM walkthrough, Scenario 4 is most effective when deployed after (or alongside) governance stabilization and capability building.

6.4.6 Scenario 5 for USM: U.S. Context Sensitivities and Stress Testing

Scenario 5 is used in the USM walkthrough as a context lens and stress test rather than a policy lever. USM operates in a U.S.-like environment where performance can respond quickly to legitimacy signals (rankings, public scrutiny, philanthropic interest) but is also vulnerable to strategic volatility (leadership turnover, budget uncertainty, political shifts). In model terms, this context strengthens some reinforcing loops but also increases the risk of decay and oscillation. For USM, this means the system should treat governance integration and cultural alignment as volatility dampeners. Scenario 5 also motivates sensitivity tests, e.g., "What happens if leadership turnover increases?" or "What happens if funding drops for two years?", to evaluate whether the USM strategy is robust under plausible disturbances.

6.5 Model Application - University of Maryland (USM Flagship)

To operationalize the dissertation's SD model for a University System of Maryland (USM) case application, the flagship campus, the University of Maryland, College Park (UMD), is used as a calibration and validation anchor due to the availability of a detailed, published AASHE STARS report with category- and credit-level scoring. UMD's STARS 3.0 submission (Gold; overall score 68.27) provides a transparent, structured set of sustainability performance indicators that can be mapped to the SD model's core constructs and used to parameterize initial conditions, calibration targets, and validation benchmarks.

As a first step, the model's observable outputs are defined as composite indices aligned with STARS scoring: (1) Strategic Commitment is proxied primarily by Planning & Administration coordination and planning indicators, including sustainability coordination, commitments and planning, and governance-related credits; (2) Sustainability Investment is proxied by Planning & Administration investment indicators; (3) Dynamic Capabilities are proxied by the campus's demonstrated capacity to measure, manage, and institutionalize sustainability practices across domains, using a weighted combination of Planning & Administration coordination and planning, relevant operations management indicators, and innovation/leadership practices; (4) Organizational Alignment & Culture is proxied by Engagement (campus engagement indicators such as outreach/communications, co-curricular activities, staff engagement and training, and culture assessment); and (5) Innovation & Entrepreneurship is proxied by Innovation & Leadership bonus indicators and sustainability research/curriculum performance as an enabling innovation base.

These mappings are anchored in UMD's reported category scores, which include strong performance in Academics (e.g., Curriculum 28.70/45; Research 23.00/23), Engagement (Campus Engagement 14.75/25; Public Engagement 20.50/25), Operations (e.g., Energy & Climate 13.12/26; Procurement & Waste 8.33/20), and Planning & Administration (Coordination & Planning 9.67/11; Investment 4.90/10).

Calibration proceeds by matching the SD model's baseline trajectory to UMD's current observed level (the 2025 STARS scorecard) and then constraining parameter values to reproduce plausible evolution consistent with the institution's strategic and operational context. Practically, UMD's 2025 STARS scores are used to (a) set initial stock levels (e.g., normalize each construct to a 0–100 scale and initialize them based on the relevant STARS category/credit composites) and (b) define calibration targets for near-term system behavior. Because a single STARS submission provides a cross-sectional snapshot, calibration is performed using a combination of: (i) structural calibration (ensuring the feedback structure and delays generate credible behavior modes), (ii) bounded parameter estimation (restricting parameters to realistic ranges for learning rates, decay/erosion rates, and implementation delays), and (iii) pattern-oriented calibration (matching qualitative patterns expected for a large research university with mature sustainability programs, such as slower marginal gains as scores approach ceiling effects). The calibration objective function minimizes weighted error between model-generated indices and STARS-based composites for Strategic Commitment, Investment, Alignment/Culture, Innovation, and an overall sustainability performance index (approximated by the total STARS score). Weights prioritize constructs most directly evidenced by STARS scorecard components (e.g., Planning & Administration and Engagement) while treating innovation/legitimacy as partially latent constructs inferred from multiple STARS components.

Validation emphasizes both behavior reproduction and robustness rather than point prediction. First, face validity and structure verification are assessed by confirming that model feedback loops produce expected directional responses: for example, increases in governance integration (Scenario 1) should raise and stabilize commitment and investment; capability building (Scenario

2) should shorten implementation delays and increase innovation; cultural transformation (Scenario 3) should reduce resistance and smooth trajectories; and ecosystem acceleration (Scenario 4) should amplify innovation-to-legitimacy reinforcement.

Second, extreme condition tests are performed by setting inputs to limiting values (e.g., very low investment or very high resistance) and confirming the model generates plausible degradation or stagnation without numerical instability. Third, sensitivity analysis is conducted on the most uncertain parameters—especially learning delays, erosion rates, and resistance elasticity—to ensure that key conclusions (e.g., the complementarity of governance, capabilities, culture, and ecosystems) remain stable across reasonable parameter ranges. Finally, cross-domain consistency checks compare model-implied outcomes with UMD's profile: for instance, UMD's strong planning/coordination and research scores should correspond to relatively high modeled strategic commitment and innovation capacity, while comparatively lower scores in some operational subdomains (e.g., Energy & Climate 13.12/26) should be consistent with modeled constraints in translating commitment into operations performance absent additional investment or capability improvements.

Several limitations are explicitly recognized in this calibration/validation approach. STARS data are self-reported and not fully verified by AASHE, which introduces potential measurement error and limits the certainty of inference from reported scores to underlying organizational states. In addition, a single published STARS report constrains traditional time-series calibration; therefore, the model's quantitative fit should be interpreted as a scenario-consistent baseline approximation rather than a high-precision forecast. To strengthen empirical grounding, the preferred next step is to assemble a multi-year panel (e.g., prior UMD STARS submissions, internal energy/GHG inventories, and facilities performance data) and recalibrate using multiple time points. Nonetheless, even with these constraints, STARS provides a rigorous, widely recognized measurement framework that supports transparent construct mapping, disciplined parameter bounding, and credible validation of structural behavior and scenario responses for the USM flagship case application.

6.6 Recommended USM Sequenced Policy Portfolio

The SD walkthrough suggests that the highest-leverage pathway for USM is a sequenced portfolio strategy: (1) stabilize commitment through governance and strategy integration (Scenario 1), (2) accelerate execution through system-wide dynamic capability building (Scenario 2), (3) reduce resistance and increase coherence through organizational cultural transformation (Scenario 3), and (4) scale visible impact through innovation ecosystem acceleration (Scenario 4), while using Scenario 5 as an ongoing stress-testing lens. This sequence is not strictly linear; cultural alignment should be continuous, and ecosystem expansion can begin early in pockets. The key principle is that USM can convert its multi-campus structure from a source of fragmentation into a source of scale by aligning governance signals, building shared capabilities, and enabling diffusion of innovation across institutions.

This policy portfolio outlines a coordinated, system-wide approach for advancing sustainability across the USM by integrating four mutually reinforcing levers: governance and strategy integration, dynamic capability building, organizational change and culture, and sustainability innovation ecosystem acceleration. Rather than pursuing these elements as separate initiatives, the package treats them as a deliberately sequenced and reinforcing portfolio designed to deliver durable, scalable, and visible sustainability outcomes across a diverse multi-campus system.

At the foundation of the portfolio is governance and strategy integration. Sustainability is embedded explicitly into system-level decision-making, capital planning, and performance oversight, with clear expectations set by the Board of Regents and senior leadership. This integration stabilizes long-term commitment, reduces vulnerability to leadership turnover, and ensures that sustainability priorities persist across planning cycles. In System Dynamics terms, this element dampens strategic decay and provides the stable platform required for other investments to mature.

Building on this foundation, the portfolio emphasizes system-wide dynamic capability building. USM leverages its scale to develop shared sustainability capabilities—such as common data platforms, analytics, training programs, and communities of practice—that reduce duplication and accelerate learning across campuses. By coordinating capability development at the system level while allowing campus-level adaptation, USM increases the speed and consistency with which sustainability strategies translate into operational and academic outcomes. This element shortens implementation delays and enables campuses with fewer resources to benefit from system-level expertise.

The third pillar of the policy portfolio focuses on organizational change and cultural transformation. Recognizing the decentralized and mission-diverse nature of USM institutions, the strategy prioritizes engagement, communication, and sensemaking that link sustainability to core academic, operational, and public service missions. Cultural alignment reduces resistance, enhances collaboration across units, and improves the durability of change. Importantly, this pillar ensures that governance signals and capability investments are interpreted as enabling rather than constraining, increasing buy-in and resilience across the system.

Finally, the portfolio strategically accelerates sustainability innovation ecosystems once governance, capabilities, and culture are sufficiently aligned. USM coordinates sustainability-oriented research, entrepreneurship, living laboratories, and external partnerships across campuses to amplify impact and visibility. By linking innovation outcomes to workforce development, community engagement, and state priorities, the system strengthens institutional legitimacy and external support. This element activates powerful reinforcing feedback between innovation success, reputation, and continued investment, positioning USM as a national leader in sustainability innovation.

Taken together, this integrated policy portfolio transforms USM's multi-campus complexity from a coordination challenge into a strategic asset. Governance integration provides stability, capability building enables execution, culture ensures coherence, and innovation ecosystems deliver scale and visibility. The System Dynamics analysis underlying this package indicates that the greatest risk to sustainability transformation is not insufficient ambition, but fragmentation and poor sequencing. By advancing these four elements as a coordinated portfolio, USM can achieve faster progress, greater resilience, and more equitable outcomes across institutions, while remaining adaptable to fiscal, political, and leadership changes inherent in the U.S. public higher education context.

The timing for a coordinated, system-wide sustainability strategy at the USM is particularly compelling given Maryland's strong policy commitments to climate action, clean energy, and equitable economic development. State-level climate targets, public sector decarbonization mandates, and increasing transparency expectations place higher education institutions under growing scrutiny to demonstrate measurable progress and responsible stewardship of public resources. As one of the state's largest public enterprises, USM has both an obligation and an opportunity to lead by example—translating policy intent into operational performance, workforce preparation, and innovation outcomes. Acting now allows USM to align governance, investment, and innovation with Maryland's long-term climate and sustainability goals, reduce future compliance and transition risks, and strengthen public trust by demonstrating accountability, fiscal prudence, and measurable impact. Delaying action increases exposure to policy shocks, reputational risk, and fragmented responses across campuses, whereas a coordinated approach positions USM as a trusted partner to the State and a national leader in public higher education sustainability.

6.7 Implementation of Sustainability Initiatives Ongoing at the USM

As concrete applications of this research, three implementation example initiatives are currently being implemented at the USM. The first is related to organizational development and change addressing sustainability issues at the system level (driven by Scenarios 1 and 3). The second relates to a marketing plan for expanding USM-wide educational offerings globally (driven by Scenarios 2, 3 and 5). The third initiative consists of an AI-enhanced approach to identifying and addressing Scope 3 carbon, water and land footprints of USM operations (driven by Scenarios 2, 4 and 5). These initiatives are being implemented under the Office of the USM Vice Chancellor for Sustainability (who is the author of this dissertation).

6.7.1 Organizational Development Towards Sustainability at the USM

The Problem and Diagnosis

The University System of Maryland (USM) has embarked on an ambitious initiative to increase its focus on sustainability issues across its education, research and operational activities. This need for change is driven by an increasing urgency to reduce the environmental footprint of the USM on natural resources such as water, energy and land, and decrease USM contributions to the global issue of climate change (USM Strategic Plan 2030). In a diagnosis phase conducted as part of this proposal (Part I), strategies towards sustainability in the USM were devised based on a review of principles of organizational development (OD), OD change processes, barriers to change and external/internal impacts. In this diagnosis, an application of Kotter's OD change model (Kotter, 2020) to sustainability in the USM emphasized how this model (or another OD model of similar scope) can be used to design of a change intervention(s) that addresses the transformation of the USM towards sustainability in its education, research and operational activities. Building on this diagnosis, the intervention design and roadmap for implementation of sustainability in the USM is the subject of this proposal, which will be submitted to USM leadership for consideration. This proposal describes the changes needed in the research, education and operational activities of the USM and the development of an OD change process that includes specific interventions to accomplish these changes. These interventions prescribe appropriate OD strategies and actions applied to the USM, following a more detailed application of Kotter's OD change model to create a change management implementation plan, identifying potential barriers and making recommendations to overcome resistance to change.

Proposed Solution - Sustainability as a Core Strategic Outcome in the USM

The USM consists of a network of 15 HEROs located throughout the state of Maryland (Figure 1-1) with a combined $7B annual budget, 40,000 employees, and nearly 200,000 students. These institutions are varied in size and scope, ranging from large research universities (e.g., UMD, UMBC, UMB) to undergraduate education focused institutions (Salisbury, Towson, Frostburg State), to historically black colleges/universities (UMES, Coppin State, Bowie State) to niche innovative institutions (UMGC, UMCES, UBalt), to regional higher education centers (southern MD, Hagerstown, Shady Grove).

Sustainability is widely recognized as one of the greatest challenges in organizational change management (Sancak, 2023; Ferrer-Estevez & Chalmeta, 2021). The involvement of a large variety of stakeholders (e.g., administration, students, faculty, staff) and areas of activity (e.g., research, education, operations) makes a transformation towards sustainability a complex change process. Although the research body on sustainability transformation or transition for business organizations is relatively new and limited, there are robust studies in organizational change management that can cast light on sustainability transformations. To transform organizations towards increased sustainability, they need leadership commitment and the ability to engage with multiple stakeholders along the value chain, widespread stakeholder engagement, and disciplined mechanisms for execution. These forces need to be harnessed to promote and enable the desired change (Khaw et al. 2023; Menon & Suresh, 2020).

To devise a strategy and action plan to implement this initiative, the USM created the office of the Vice Chancellor for Sustainability (VCS), which is charged with developing a Sustainability Action Plan (SAP) for the USM and shepherding its implementation. This proposal outlines the stages, strategies and interventions that will constitute the SAP for the USM, as shown in Table 6-2. The proposal includes an OD framework for implementation and assessment/evaluation under the office of the VCS, working with participation and coordination of sustainability teams that are either already existing or to be built across the 15 USM HEROs. An overview of existing staff and organizational structure of sustainability teams across all HEROs needs to take place, identifying synergies that can be achieved by increased collaboration across institutions on sustainability matters, focused on achieving efficiencies in areas of activity such as research, e.g., joint research projects leveraging relevant expertise of faculty; education, e.g., joint educational offerings on environmental sustainability topics, majors, and degrees; and operations, e.g., procurement is a key area of sustainability focus given that the environmental footprint (water, energy, land) of an organization is composed of up to 80 percent on its purchasing practices (CDP, 2021; Valls-Val & Bovea, 2022; Thurston & Eckelman, 2011). Additional stakeholders that need to be engaged in the development and implementation of this SAP are the USM Board of Regents, which is the state-appointed governing body of the USM that approves budgets as well as organizational changes and needed investments for all 15 HEROs in the USM; the leadership of the HEROs (15 Presidents and their executive teams), who need to incorporate the SAP strategies and actions into their research, education and operational activities; and external stakeholders of the USM, e.g., funders in the state and federal governments, private industry and non-profit institutions.

Table 6-2: Sustainability USM Change Process Stages, Strategies, Interventions and Timeframe for Implementation
(source: prepared for this research)

Change Stage (Kotter Model)	Organizational Development Strategies	Recommended Intervention(s) and Timeframe for Implementation
1 – Establishing a Sense of Urgency	The move towards sustainability is a planned change effort by the USM. However, the effort so far has been made top-down, so increased efforts need to be devoted to internalizing the need for change within the 15 USM institutions.	• Visits to all 15 institutions to be carried out, interviewing personnel involved in sustainability activities in research, education and operations. (3 mo) • Develop an inventory of existing sustainability activities, including scope, budget, human resources allocated, and data on current state, results or outcomes achieved (to date and projected). (9 mo)
2 - Creating a Guiding Coalition	All 15 USM institutions have some form of sustainability-focused organization, and these can serve as an initial group of change champions. However, there is a large variation in scope and resources among these that can make the change	• Identify change stakeholders outside of the existing "supply" side of sustainability staff, constituting a "demand" side that can complement the coalition. (6 mo) • Use this expanded coalition to develop a baseline for alignment and coordination, that can serve as a common understanding of

	effort challenging. This implies the <u>need to refine/augment a guiding coalition</u>.	the current state of sustainability challenges across the research, education and operation areas of the USM. (9 mo)
3 – Developing a Vision and Strategy	This is the current stage of efforts for sustainability at the USM. Awareness exists and there is a common understanding of the need for organizational change, but a <u>specific diagnosis</u> still needs to be formulated, qualitative and quantitative <u>data needs to be collected</u>, and a <u>process to accomplish this change needs to be devised</u> (DiPofi, 2002; Verhoef & Casebeer, 1997).	• Develop a draft vision for an increased focus on sustainability to be shared widely within the USM community; future-ready education, net-zero operations, transdisciplinary research. (12 mo) • Identify data gaps and develop a draft data collection plan across that integrates the research, education and operations activities of the USM. (12 mo) • The guiding coalition will be constituted into a steering group to guide the development of a "Sustainability Action Plan" (SAP) for the USM. (14 mo)
4 – Communicating the Change Vision	The guiding coalition (champions) will be leveraged to <u>create a communications plan</u> across the USM to promote engagement	• Working with the steering group, the vision, required data collection efforts and the need for a SAP for the USM will be assembled into a communication strategy. (12 mo)

	with the proposed change(s). This effort will be focused on identifying barriers (both internal and external), minimizing and managing resistance to change (Menon & Suresh, 2020).	• A consultant (or consulting firm) will be retained to devise, and implement a communications plan that engages audiences internal and external to the USM; this may also be accomplished working with the office of the USM Vice Chancellor for Marketing & Communications. (15 mo)
5 – Empowering Broad-Based Change	In an organizational setting as large and complex as the USM, it will be important to coordinate efforts centrally to achieve consistency but delegate the autonomy and responsibility to the 15 institutions to “seed” the effort and generate momentum towards the desired change (Vlachopoulus, 2021).	• Evolve the steering group towards a structure that can facilitate USM-level consistency while enabling institution-level specific action for implementation of the SAP. (16 mo) • Expand the reach of the steering group at the institution level by leveraging and/or augmenting the existing sustainability teams. (18 mo)
6 – Generating Short-Term Wins	Short-term gains will require prioritization. Changes in USM operations will be likelier to be achieved in the short-term, e.g.,	• On operations, analyze supply chain and specifically purchases to identify short-term actions that can enhance progress towards sustainability goals. (12 mo)

	enhanced efforts towards energy efficiency, water and carbon emission net-zero facilities. Changes in educational curricula and research activities are expected to take longer, which will require managing resistance by university faculty and administration, and state curricula accreditation processes (Ferrer-Estevez & Chalmeta, 2021).	• On education, identify curriculum integration opportunities that can be synergized across USM institutions (e.g., Marine Science, Environmental Management, Computing) and promoted through the USM institutions and accreditation processes. (15 mo) • On research, identify opportunities for investments in initiatives that promote sustainability and leverage talent across USM institutions, e.g., circular economies, sustainable cities, resilient supply chains, earth system science & technology. (18 mo)
7 – Consolidating Gains and Producing More Change	As changes in operational activities start to be achieved, increased focus will be placed on education and research activities of the USM. Incentives and rewards will be identified and put in place to enable and	• Assess sustainability activities in research, education and operations; this will require the development of activity-specific KPIs. (18 mo) • Institutionalize successful experiences by allocating resources, i.e., human, budget. (21 mo)

	accelerate change in these areas (Gkrimpizi et al., 2023).	• Develop incentive structure for innovation towards new/enhanced sustainability activities. (24 mo)
8 – Anchoring New Approaches in the USM Culture	Monitoring, evaluation and learning (MEL) mechanisms will be developed and put in place to anchor the planning and management of sustainability efforts across the USM towards further improvements and institutionalization of these efforts (Traeger & Worwick, 2018; Karasvirta & Teerikangas, 2022).	• Establish a mechanism to take stock of lessons learned through implementation of the SAP. (20 mo) • Align scope and budget of USM sustainability efforts including representation and participation of all institutions. (24 mo) • Consolidation and institutionalization of a USM-wide working group coordinated by the office of the VCS. (24 mo)

Evaluation – Implementation and Assessment

The implementation of the proposed move of the USM towards an increased focus on sustainability across its research, education and operational activities taking place in its 15 HEROs is expected to be carried out over a 2-year period as detailed in the different OD interventions staged in Table 6-2. A comprehensive roadmap towards success of includes factors such as committed leadership, incentives and rewards towards change, data-driven management and decision-making, effective investments, monitoring of outcomes, evaluation and learning (Khan et al. 2025; Koutsioumpa, 2023; Pant, 2023).

Tracking implementation towards progress along the timeframe of this proposed intervention will be facilitated by the development of Key Performance Indicators (KPI). Several KPI frameworks exist for tracking progress towards sustainability in organizations (Ferrari et al. 2025; Angelaki et al. 2024). The 17 Sustainable Development Goals (SDG) developed as a part of the United Nations 2030 Agenda for Sustainability Development has been used as tool to measure and map how institutions are linked with sustainability (SDSN, 2017; Rajabifard et al. 2021; Pinto et al. 2025); this framework is currently used by peer institutions such as Arizona State University, George Mason University and the University of Maryland at College Park (Spaulding et al. 2025). Another relevant framework that has been refined and widely applied at HEROs is the Sustainability Campus Index (AASHE, 2024), which provides a consistent template for HEROs to assess progress towards sustainability across several institutional activities that include research, education and operations. Devising a set of KPI will be part of the implementation and assessment of this OD change proposal.

It is important to reiterate the role of leadership towards sustainability in the USM, particularly as it relates to resistance to change. In addition to commitment from the senior leadership at the USM (Chancellor's Office and Presidents of the 15 HEROs), it is recommended that continuity of the role of the steering group is institutionalized through the office of the VCS. Such a "sustainability leadership network" across the USM will facilitate activities such as monitoring of performance through the KPIs, management of barriers and resistance to change against the proposed change(s) in areas such as organization, administration, strategy, technology, people and culture (Gkrimpizi, 2023; Cuesta-Claros et al. 2024; Ruiz-Mallen & Heras, 2025; Shaya et al. 2025).

Summary and Next Steps

This proposal (now being implemented) documents an OD planned change towards an increased focus on sustainability across the 15 HEROs in the USM. Building on a previous diagnosis, this proposal outlines a comprehensive set of strategies and interventions staged using Kotter's OD change model. This intervention addresses the transformation of the USM towards sustainability in its education, research and operational activities. This change proposal will be presented to USM leadership for consideration and possible implementation over the next 2 years. Recommended next steps and investments for implementation and assessment are made, including the establishment of a sustainability leadership network/group to steer the process forward, managing barriers and resistance to change, working across all 15 HEROs and a comprehensive group of external stakeholders, as well as developing a set of KPI for tracking and assessment of progress towards the desired change.

6.7.2 UMCES 100 Marketing Plan "From Bay Beginnings to Global Impact"

Summary

As it turns 100 years since its founding in 1925, the University of Maryland Center for Environmental Science (UMCES), which is one of the HEROs in the USM, stands at a critical juncture among the premiere environmental science research and education organizations around the world. UMCES needs to diversify its sources of revenue, grow its enrollment and research output, and increase impact globally to fulfill its strategic goal of becoming one of the world's leading environmental universities. This marketing plan outlines our strategy to achieve a target of 33 percent of share of overall revenue portfolio from non-governmental sources, increase our graduate enrollment to reach a student-to-faculty ratio of 3:1, and expand our educational reach globally through an expanded portfolio of online degrees and services.

Market analysis supports our degree offering expansion strategy for workforce development, addressing demand and job opportunities, and increase of the pipeline of graduate students to fuel growth of our research revenue from non-state/federal sources. UMCES will offer a new series of degree programs in environmental science through expansion of online offerings at the graduate and undergraduate levels. The marketing mix for online degree offerings position UMCES as the trusted, applied science leader for flexible, career-driven research and education in environmental and sustainability fields. This marketing mix aligns the unique strengths represented in its brand: *scientific excellence*, *applications and career-focused*, *flexibility*, and *impact*, with market demand for quality/credible, flexible, applied, and career-oriented environmental credentials.

A 12-month development and deployment schedule has been structured in 4 phases with key actions, budget focus, and performance checkpoints. An estimated resource development plan for the first year of implementation was developed with a target ROI of 100 new students generating $1M+ in new revenue. The estimated budget needed for deployment is $250,000 annually. Performance of development and deployment of this plan will be monitored and assessed through a marketing metrics dashboard.

Situation Overview and Goals

Mission:

The mission of UMCES is to conduct research and educate the next generation of scientists to take on the world's environmental challenges. This mission drives the research and educational programs we conduct with students and services to other stakeholders in the public (state and federal) and private (industry and non-governmental organizations) sectors, as well as international customers.

Product Description:

The portfolio of products provided by UMCES to its customers can be broken down into three major categories, making it a diversified portfolio. *Research*: scientific investigations into customers' needs that requires the generation of new knowledge (i.e., respond to a problem that has not yet been solved). *Education*: UMCES offers the *Marine, Estuarine and Environmental Science* (MEES) graduate program at the master and doctoral levels. *Service*: customized applications of environmental science to solve a customer need, typically to a higher degree of specialization than a consulting company can provide.

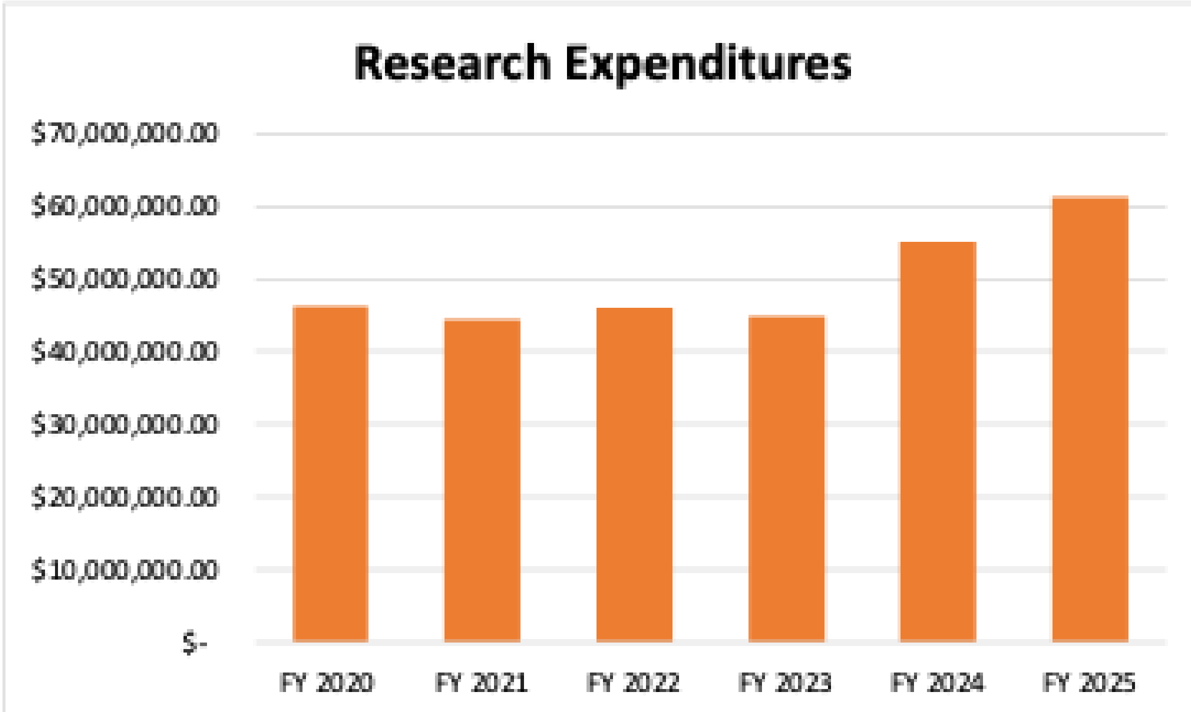

Figure 6-1*: Research Expenditures at UMCES (FY20-25; FY=Fiscal Year)*
source: prepared for this research with data provided by UMCES

Current Value Perception:

The current value perception of UMCES can be characterized as prestigious and highly valued, but stagnant. This is evidenced by primary data collected for this marketing plan across its portfolio of products, both internally and externally. Data from the last 6 years display a relatively flat (stagnant) level of research expenditures. These expenditures reflect revenues from grants and contracts awarded to UMCES (Figure 6-1). When these expenditures are broken down by funding (revenue) source, it can be observed that UMCES' primary research customers are the state of Maryland and the federal government, with many other potential customers, e.g., businesses, industry, non-governmental organizations, not the focus of current and past marketing efforts (Figure 6-2). With respect to education, the enrollment of students at UMCES shows a similar stagnant trend, averaging approximately 100 graduate students, but with a declining trend over the same period (Figure 6-3).

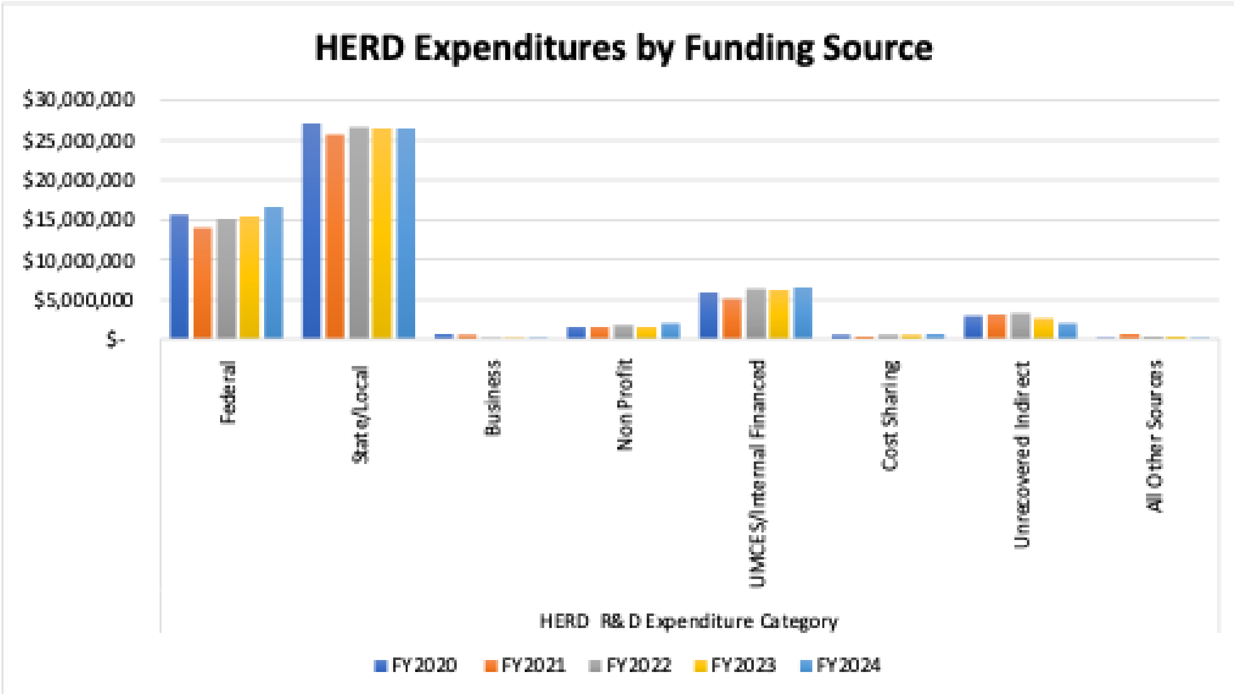

***Figure 6-2**: Higher Education Research and Development Expenditures (FY20-24). source: prepared for this research with data provided by UMCES*

Internal Environmental Scan:

UMCES has a clear 2:1 return-on-investment when comparing investment by the state of Maryland with research expenditures (Figure 6-4). This ROI shows capacity to generate revenue that can be leveraged towards other sources of funding. The environmental science areas span a broad spectrum of needs that are relevant to a variety of customers, a broader scope than those currently served in the state and federal sectors. Figure 6-5 shows an analysis done by the World Economic Forum (2025) which identifies environmental risks posing significant impacts to businesses' bottom line and having a high likelihood of materializing. UMCES works across all these problem areas.

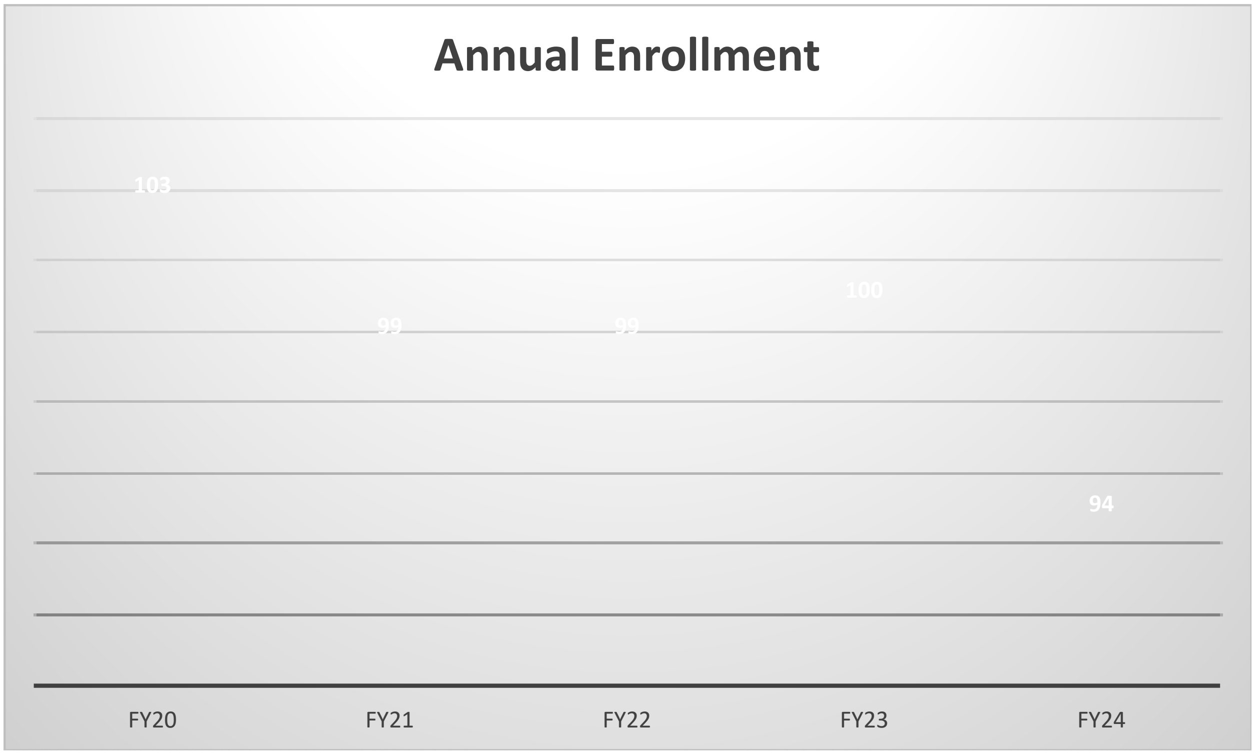

Figure 6-3*: Graduate Student Enrollment at UMCES (FY20-24).*
source: prepared for this research with data provided by UMCES

In addition to its traditional master and doctoral graduate programs, there is an opportunity to provide workforce and capacity building activities such as professional development (e.g., short courses, in-service training) adult education (e.g., graduate and professional certificates) and online delivery of programs which offer the potential to reach customers worldwide.

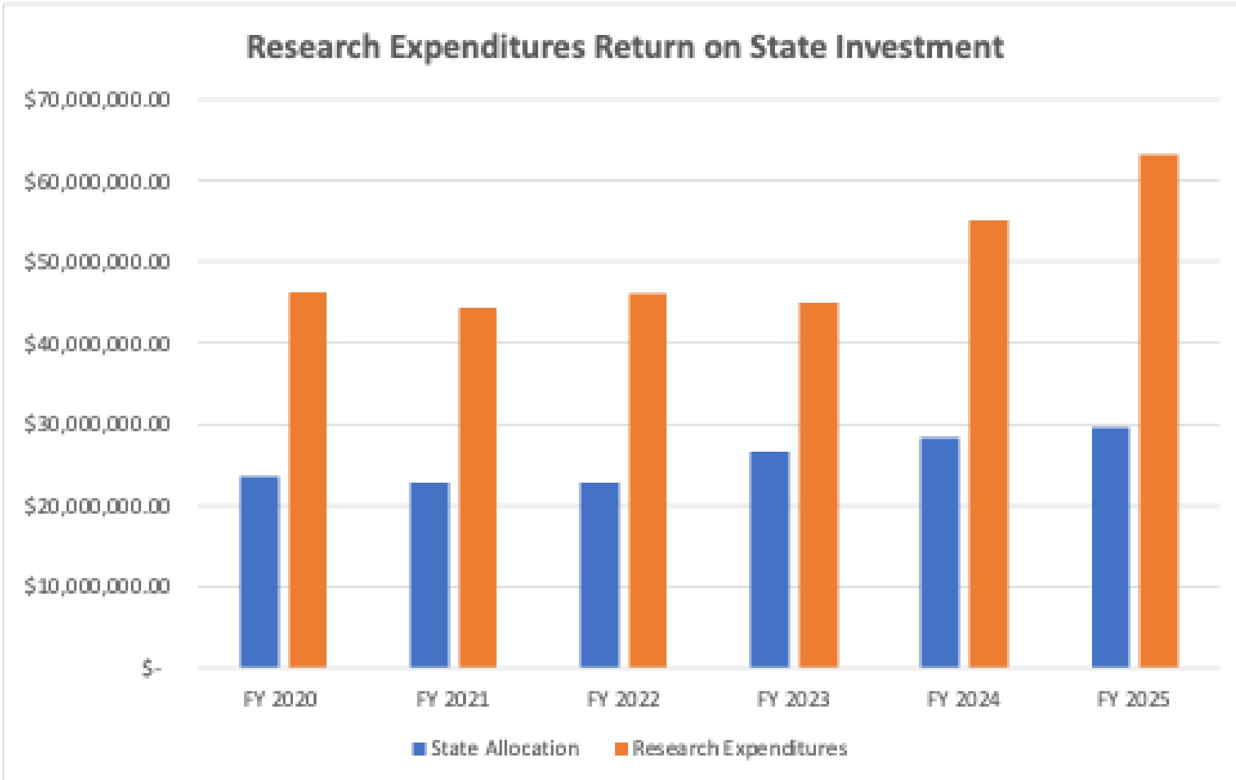

Figure 6-4: *Comparison of state of Maryland funds invested in UMCES vs research expenditures (FY20-25). source: prepared for this research with data provided by UMCES*

External Environmental Scan:

UMCES is well known for the quality of its research, education and service products. Table 6-3 shows a compilation of data of UMCES vs key competitors across the country, indicating UMCES being the 3rd nationally ranked environmental science institution (using research expenditures as an indicator) and ranked 223 among all universities nationally. Founded in 1925, UMCES has a century-long history of providing impactful environmental science, particularly regarding the Chesapeake Bay. For the last 100 years, UMCES has built a reputation by effectively translating complex scientific data into accessible visuals for policymakers and the public.

The almost exclusive dependence to date on state and federal sources of funding has limited the experience of the institution and reduced its competitiveness in today's market, keeping UMCES away from opportunities such as those identified by the private sector (Figure 6-5). With an expansion of its customer base to include private companies, non-governmental organizations and others with a stake on the environment and the use of natural resources, the potential for growth in research expenditures exists and needs to be carefully approached through strategic planning. Currently the student-to-faculty ratio at UMCES is 1.3:1, while this number should get closer to 2:1, as some of its competitors have achieved (e.g., Woods Hole). Given the number of faculty at UMCES, this is an area of opportunity.

***Figure 6-5**: Risks to industry/business bottom lines; source (World Economic Forum, 2025).*

Table 6-3: *Benchmark comparison of UMCES with key competitors in the environmental science research, education and service market (UCSD=University of California, San Diego; ESF-SUNY=Environmental Science and Forestry, State University of New York; VIMS=Virginia Institute of Marine Science, College of William & Mary). source: prepared for this research with data provided by National Science Foundation (NSF)*

Environmental Institutions that Reported Expenditures to NSF HERD from 2010-2023						
Institution	FY 2023 Total Dollars in Research Expenditures	FY 2023 Total Dollars in Federal Expenditures	% Total Funding Federal	Number of Faculty	Number of Students	NSF HERD Rank
Scripps (UCSD)	485,435,000	272,181,000	56%	235	350 (G)	66
Woods Hole Independent	262,048,000	222,351,000	85%	250	500 (G)	108
UMCES (USMD)	51,201,000	14,072,000	27%	78	96 (G)	223
ESF (SUNY)	28,440,000	6,979,000	25%	134	1745 (U) 373 (G)	257
VIMS (W&M)	20,365,000	16,641,000	~80%	56*	100 (G)*	300s

Critical Issues:

Market analysis identifies several critical issues requiring immediate strategic attention First, *UMCES needs to diversify its revenue sources*. Currently, its practically exclusive dependence on state and federal sources makes it vulnerable to government budget shortfalls like those currently taking place, while not being able to realize revenue from other sources that have needs for environmental science services and products, as evidenced in Exhibit D-5. Second, *UMCES has the capacity and the opportunity to increase the footprint of its educational offerings*. This can be achieved by marketing efforts aimed at an increased enrollment in its graduate programs to increase its student-faculty ratio, as well as by enhanced efforts in providing expanded workforce and professional development programs. Finally, *UMCES needs to develop an institutional* *culture that is more customer-oriented*, focused on value creation, having a clear value proposition, working towards identifying its target market(s) and adapting its market offering(s). As predominantly a state/federal funded organization, UMCES has not had any focus on marketing efforts, so an identification of the target market using tools such as the 5-C Framework (Chernev, 2019) has never been done. This gap in marketing efforts is a challenge and an area of potentially significant opportunity.

Goal and Objectives:

Following current market trajectory and analysis (benchmarks from competitors in Table 6-3 and evidence of market needs for environmental science, our primary strategic goal is to become one of the world's leading environmental universities. We intend to achieve this goal within the next 3 years by focusing on: (i) achieving a target of 33 percent of share of overall revenue portfolio from sources other than the state of Maryland or the federal government; (ii) increase our graduate enrollment to reach a student-to-faculty ratio of 3:1; and (iii) expand our educational reach globally to working professionals, recent graduates and international students through an expanded portfolio of online degrees and services.

Strategy and Market Analysis

Marketing Research:

The global academic research and development (R&D) market is estimated at USD 580 billion in 2025, projected to reach about USD 812 billion by 2029, growing at roughly 8.7% CAGR (Research and Markets, 2025). A subset of this data, environmental science research, while not broken out separately, is a growing share as public and private funding prioritizes climate, ecology, and sustainability domains. In the US, R&D spending in environmental sciences at academic institutions has grown more than 8-fold over the past 50 years (from $1.2B in 1973 to $10B in 2023, in constant 2017 dollars), reflecting a sustained 4.4 % CAGR (National Center for Science and Engineering Statistics, 2025).

Environmental science degree programs in the US are rising; awards increased 24% since 2016 (Keystone Education Group, 2022). Environmental science graduates in the US were 436,000 in 2023, growing nearly 5% annually (Data USA, 2025). The Bureau of Labor Statistics estimates that environmental scientists and specialists are projected to see job growth of 4% from 2024 to 2034, with 8,500 job openings annually, driven by replacing retirements and steady demand from consulting, regulation, planning, and corporate sustainability efforts (US Bureau of Labor Statistics, 2025).

Target Market Analysis:

The core competency of UMCES is the ability to generate, integrate, and translate environmental science into actionable knowledge for managing and sustaining ecosystems while training the next generation of environmental leaders. This competency attracts customers that span multiple segments: students seeking graduate degrees in environmental science, government agencies and policy makers seeking advice on regulatory matters, environmental non-governmental organizations seeking scientific support, and working professionals worldwide in a variety of industries in the private sector, e.g., energy, food, water, development and real estate that require environmental information for their operations. These personas represent both paying customers (degree and upskilling seekers, research sponsors, consulting clients, laboratory services) and stakeholder audiences (graduate students, community, policy makers) critical to UMCES's mission of "science for the environment." This brings a significant alignment of customer value and customer profile.

UMCES customers share a common value for scientifically credible and actionable environmental information. The profile of these customers is characterized by several factors that also define their target attractiveness. Demographic factors include the age range 25-35 for recent graduate and young professionals and 30-50+ for experienced workers seeking upskilling. Geographic factors common across all customers indicate they are mostly coming from within Maryland, or other locations in the US and globally that share similar environmental characteristics: a mix of mountain to coastal, urban and rural environments undergoing development. Behavioral factors related to these customers are their pursuit of professional specialization and career advancement in the case of students, and operational investments and expenses in the case of industry, NGO and government clients. Psychographic factors in these customers reflect the pursuit of a surrounding environment of improved quality, e.g., clean air, clean water, green spaces, for aesthetic, commercial or regulatory compliance purposes.

Company Structure and Collaborations:

The distributed structure of UMCES 6 lab locations throughout the state of Maryland enables the development of skills to tackle environmental problems from "mountains to oceans and from genes to ecosystems". Field stations in these locations enhance our ability for accelerated on-the-ground innovation and responsiveness to our customers. Industry studies show this structure aligns with best practices for global science and technology-driven organizations (Kotler et al. 2022).

Building relationships of strategic and tactical value with the private sector (e.g., Chesapeake Bay Foundation, The Nature Conservancy) in the state and beyond provides valuable customer touchpoints and brand positioning opportunities. Partnerships with online education providers such as edX to deliver classes in our graduate programs as well as professional development short courses have significantly extended our digital reach. Our collaboration with private impact investors such as TALIN (*The Appalachian Laboratory Investors Network*) and the Ratcliffe Foundation has yielded substantial seed funding for entrepreneurial research and education innovation and incubator activities.

Competitive Landscape:

As an environmental science research and graduate education organization, UMCES competitors fall into regional peers and national-global centers of excellence. These organizations compete for federal and state research funding and graduate students in environmental science. Regionally, UMCES' closest competitors are the Virginia Institute of Marine Science (VIMS) and the SUNY College of Environmental Science and Forestry (ESF) Environmental Science and Forestry (ESF)**,** both of which focus heavily on environmental research and training of young scientists, directly overlapping with UMCES's core mission. At the **n**ational level, the Woods Hole Oceanographic Institution (WHOI) and the Scripps Institution of Oceanography (SIO at UC San Diego) attract top graduate students and major research revenue in marine and climate science (Table 6-3).

UMCES's niche advantage is trusted applied environmental science for Maryland, strong faculty reputation, locations offering a variety of hands-on field and laboratory opportunities and research with direct policy impact. Competitors either share the same geographical focus on state-level research and education (VIMS, ESF), or compete at the global level with similar fundamental, high-profile environmental science (WHOI, Scripps).

Economic and Regulatory Context:

UMCES is a public research institution designated within the University System of Maryland, with a state legislative mandate to conduct mission-driven marine, estuarine, and environmental science research that supports state policy in areas like Chesapeake Bay management, water quality, and ecosystem restoration. Through this mandate, UMCES plays a significant applied science role in economic development, leveraging partnerships with local government and industry to translate science into innovation and jobs. Its market environment is closely tied to Maryland's environmental regulatory regime and state-sponsored science initiatives, particularly around Chesapeake Bay health, clean energy technologies, and climate adaptation.

Recent federal reductions in budget allocation towards scientific research activities, and environmentally focused areas in particular (e.g., climate change, renewable energy) have brought significant uncertainty to UMCES funding sources, stressing the need to diversity its customer base and revenue portfolio.

Value Proposition and Positioning:

Consumer perception surveys and interviews that have been conducted as part of an ongoing strategic planning process shape our core value proposition of *applied, policy-relevant environmental science with direct societal impact in Maryland, but scalable nationally and globally*. Market research across all customer segments validates our positioning *of integration "under one roof" of cutting-edge environmental scientific research with expanded options in education and workforce development*, and the differentiation of UMCES as the *fastest translator of science to solutions, owning the "Maryland-to-World" narrative, and leading public-private collaborations with stakeholders for scale and impact*.

Development and Deployment

Product and Service Components:

Market analysis supports our degree offering expansion strategy for workforce development (addressing demand and job opportunities) and increase of the pipeline of graduate students to fuel growth of our research revenue from non-state/federal sources [6-9]. UMCES will offer a new series of degree programs in environmental science through expansion of online offerings as follows: (i) a professional (practice-oriented) graduate program in Environmental Management at the masters (MEM) and doctoral (DEM) levels; (ii) expansion of our research-focused MEES program with hybrid options (online + in person) at the masters (MS) and doctoral (PhD) levels; (iii) tailored and stackable graduate level certificates (fully online) in areas such as climate adaptation, coastal resilience and environmental intelligence and data analytics; (iv) a fully online undergraduate degree (BS) in Environmental Science.

This new degree program series represents a significant expansion of our current offerings (the existing MEES program MS and PhD degrees are offered only in-person) and will drive the expansion of our customer base domestically outside of MD and the mid-Atlantic region to the rest of the US, and internationally through our enhanced online presence and delivery. The new degree programs will be complemented with two supporting and enhancing offerings: micro credentials which can be stacked towards graduate certificates and master's level degrees; and free/courtesy research and professional webinars to enhance visibility of our degree programs and generate leads for student recruitment.

Key support services that will be offered jointly with this new line of degree programs are focused on two major areas: academic advising and technical support. Academic advising services will include learning success coaching to help plan courses, admissions, registration, degree requirements, stay on track, graduation, career mentoring and planning assistance (resumes, job search, networking), wellness and mental health services (counseling, peer-support, wellness line). Technical support will include a Help Center with real-time phone/chat for issues with online classes or course platforms as well as assistance with online classroom tools and electronic class materials.

Marketing Mix Integration:

The marketing mix for online degree offerings seek to position UMCES as the trusted, applied science leader for flexible, career-driven research and education in environmental and sustainability fields. This marketing mix aligns the unique strengths represented in its brand: *scientific excellence*, *applications and career-focused*, *flexibility*, and *impact*, with market demand for quality/credible, flexible, applied, and career-oriented environmental credentials. We have developed a tailored marketing mix strategy developed using the 7T framework (Kotler et al. 2022): product, service, brand, price, incentives, communication, and distribution.

Our *product* line consists of the new degree programs outlined above, including linked *services* with these offerings. Marketing for the new UMCES degree offerings will incorporate a messaging architecture conveying the UMCES *brand*'s core value proposition and positioning to key audiences. The plan will message *scientific excellence* ("learn from nationally recognized environmental scientists"), *applications and career-focus* ("master practical tools like GIS, environmental intelligence and data science for careers in sustainability"), *flexibility* ("100% online with optional field intensives"), and *impact* ("join a network that shapes environmental sustainability locally, regionally and globally") to working professionals ("boost your credentials with a respected, flexible program built for government and industry environmental applications"), recent graduates ("turn your science degree into impact with environmental data and policy expertise"), international students ("learn from a US leader in environmental and sustainability science"), and employers ("partner with UMCES to train your team in sustainability and compliance").

The *pricing* model devised for the new line of UMCES online and hybrid programs signals the prestige and quality associated with the UMCES brand, while providing high ROI for customers seeking professional advancement and reskilling (employees in government, consulting companies, NGOs), recent graduates seeking specialization in environmental science (wide funnel) and international students seeking the global appeal of US-based degrees and credentials. This pricing is competitive with respect to key competitors in the online environmental science education market and includes *incentives* designed to address market demand. Micro credentials will be priced at $300-$500, with convenient stacking towards graduate certificates. Graduate certificates will be offered in the range $2,000-$4,000, including bundling into our graduate degree programs (MEM/MS). The online professional MEM and DEM programs will be offered at $15,000 and $25,000, respectively, with the MEM coursework directly applicable towards the DEM (or the PhD). The hybrid research MS and PhD programs will be offered at $20,000 and $30,000, respectively, with the MS stacking onto the PhD (or the DEM); these hybrid programs include on-site experiences of 2 weeks per year ("field intensives"), with additional/optional field intensives available at $5,000 each. The fully online BS in Environmental Science will be offered at $30,000 with scholarships available through funding provided by UMCES philanthropic sources (corporate and individual donors).

The *distribution* model for delivery of the portfolio of degree programs is 100% online (with optional hybrid elements in the MS/PhD as noted), using an asynchronous core for flexibility complemented with synchronous activities (e.g., seminars, live Q&As). Course material delivery will be made through the well-established online platform University of Maryland Global Campus (UMGC) worldwide. Partnerships with edX and Coursera will be explored to amplify reach globally.

A multi-channel *communication* strategy will employ a combination of: (i) owned media, e.g., UMCES revamped website as the landing hub, the UMCES institutional blog for thought leadership, and email campaigns for lead nurturing; (ii) paid media for lead generation, e.g., google ads in searches related to environmental science degrees, Linkedin ads with sponsored content in job searches in environmental fields, facebook/Instagram ads for targeting and awareness in early career and younger audiences; (iii) earned media to enhance credibility, e.g., press releases announcing degree program launches, faculty op-eds on environmental issues, media partnerships with environmental sustainability publications (GreenBiz), webinars with partners in government, industry and NGOs.

Development and Deployment:

For purposes of launching and filling first cohort(s) of online graduate programs and certificates, establishing brand awareness, and building a sustainable enrollment funnel, a 12-month development and deployment schedule has been structured in 4 phases with key actions, budget focus, and performance checkpoints. Table 6-4 presents a breakdown of the key actions, deliverables, estimated budget and KPIs of each phase.

Phase 1 - Strategy and Setup (Months 1-3) builds the foundation, assets and internal alignment for the launching of the new degree programs. Phase 2 - Awareness and Lead Generation (Months 3-6) drives visibility, builds interest and generates leads. Phase 3 – Nurture and Conversion (Months 7-9) converts interest into applications and enrollment. Phase 4 – Enrollment and Scaling (Months 10-12) finalizes the first cohort(s), refines funnels, and prepare for next cycle.

An estimated resource development plan for the first year of implementation was developed with a target ROI of 100 new students, consisting of a mix of micro credential + grad cert + degree students (BS/MEM/DEM/MS/PhD) generating $1M+ in tuition revenue based on the proposed pricing model. The estimated budget needed for deployment is $250,000 in Year 1 (with a similar figure going forward), broken down in Table 6-4. Performance of development and deployment will be monitored and assessed through the metrics dashboard shown in Table 6-5.

***Table 6-4**: Development and Deployment Schedule for UMCES Online Graduate Offerings Rollout (source: prepared for this research)*

Month	Key Actions	Deliverables	Est. Budget	KPIs
1	Market segmentation & program definition	Buyer personas (gov't, NGO, consulting, data science professionals) Competitive pricing analysis	Internal	Personas complete
1–2	Brand messaging & creative assets	Tagline, logo variants for online programs Landing pages (SEO-optimized) Faculty photos, video intros	$15k	Website ready
2–3	Platform setup & CRM integration	CRM (e.g. HubSpot or Slate) for lead tracking	$10k	Funnel tracking live

Month	Key Actions	Deliverables	Est. Budget	KPIs
		Email automationAnalytics dashboards (Google Analytics, LinkedIn Insight Tag)		
3	Soft launch microsite	"UMCES Online" hub live Program guides downloadable	Included above	100+ web visits
4	Launch digital ad campaigns	Google Ads (search keywords: "online environmental science degree") LinkedIn Ads (target job titles)- Retargeting setup	$10k/mo	500+ leads
4–5	Content marketing rollout	3–4 blog posts/month Video series: "Inside Environmental Science" Social posts weekly	$4k/mo	+10% monthly traffic
5	Webinar Series	"Careers in Environmental Data Science"	$2k	100+ attendees

Month	Key Actions	Deliverables	Est. Budget	KPIs
		"How to Upskill for Sustainability Jobs"		
6	PR launch	Press release: "UMCES launches online programs" media outreach (local & national)	$3k	5+ media mentions
7	Email nurturing campaigns	Automated sequences: "Program Overview", "Career Outcomes", "Apply Now"	$2k	20% email open rate
7–8	Personalized outreach	Admissions counselors contact high-fit leads Offer advising sessions	Staff time	50+ consults
8	Offer incentives	Early application fee waiver- "Founding cohort" scholarships	5 x $10k scholarships	10+ enrollments
9	Application drive	Application deadline campaign- Countdown emails + social push	$3k	50+ applications

Month	Key Actions	Deliverables	Est. Budget	KPIs
10	Orientation & onboarding content	Welcome webinars Virtual campus tour Faculty meet-and-greet	$2k	90% retention
11	Data review & optimization	Analyze lead sources, conversion rates Refine ad targeting	—	CPL < $100
12	Next cycle prep	Adjust creative materials Update web copy & outcomes Launch alumni stories	$2k	+20% leads vs. cycle 1

Table 6-5: *Key Performance Metrics Dashboard for UMCES Online Graduate Offerings Rollout (source: prepared for this research)*

Funnel Stage	Metric	Target
Awareness	Website visits	20,000/year
Lead Generation	Qualified leads	2,000
Engagement	Webinar attendance	300
Conversion	Applications	150
Enrollment	Students enrolled	75–100
Retention	Program continuation	90%

6.7.3 Sustainability Innovation Proposal – Terra HEROs

Managing the Environmental Footprint of Supply Chains in University Systems

As most higher education institutions and university systems around the world, the University System of Maryland (USM) has embarked on an ambitious initiative to increase its focus on sustainability issues across its education, research and operational activities. This initiative is driven by the need to create a competitive advantage as sustainability is a desirable ("must-have") attribute sought for in today's higher education (AGB Search, 2025; AASHE, 2025; The Princeton Review, 2025). At the same time, there is an increasing urgency to reduce the environmental footprint of the USM on natural resources such as water, energy and land, and decrease USM contributions to the global issue of climate change, both for environmental and cost reasons (USM Strategic Plan 2030). The solution proposed identifies opportunities for cost-savings and management of environmental footprint through sustainable supply chain analysis implementing artificial intelligence tools. The primary group served is *university system leadership* who, in the case of the USM where this solution will be implemented, provide the services of oversight and management for 15 higher education and research organizations (HEROs) located throughout the state of Maryland with an $8B annual budget, 40,000 employees, and over 170,000 students.

As our new USM venture *Terra HEROs* transitions from concept to full implementation, it scales operations by gradually expanding its target market (niche -> mainstream) building a resilient service delivery model grounded in modular AI technology development starting with a minimum viable product (MVP) for innovators and early adopters (Levine, 2025) and a phased customer onboarding approach. Financial sustainability is achieved through a diversified revenue portfolio: UMCES will bootstrap the venture during its first 2 years, complemented by grant funding and moving to generating revenue from subscriptions by other USM institutions and beyond, developing vendor licensing opportunities, professional development courses and gradually reducing dependence on grant funding in Years 3-5. Risk is proactively managed through robust data governance, cybersecurity protocols, transparent AI practices, and well-defined operational controls that safeguard institutional trust and platform reliability. To track success, the venture establishes clear performance metrics including model accuracy, customer adoption and retention, reductions in Scope 3 hotspots for carbon/water/land, vendor participation rates, and revenue-to-expense ratios. By coupling disciplined financial planning with scalable systems, risk-conscious operations, and measurable outcomes, *Terra HEROs* evolves from a promising innovation into a mature, operationally sound, and impact-driven sustainability enterprise.

Customer Segment

The user group for the proposed solution is composed of HERO leadership, e.g., USM Board of Regents, Chancellor and Vice Chancellors, Presidents and their institutional management teams. This user group is defined by senior administrators, middle-to-high income, graduate level education and 10 years or more of professional experience. These individuals are generally environmentally conscious, commercially driven and budget-minded given their fiduciary responsibility to university system shareholders. They live nearby to where their HERO is located; in the USM case, this is the state of Maryland and vicinity. HEROs are highly scrutinized by public and/or private stakeholders which translates into this user group being resistant to change and risk-averse.

Problem

Efforts in environmental footprint management by companies across sectors has focused on greenhouse gas (GHG) emissions in direct operations (Scope 1) and use of energy through utilities (Scope 2); other efforts worth noting are increased operational efficiencies in the use of other natural resources such as water. More comprehensive efforts have tackled the reduction of GHG (carbon) footprint in supply chains, referred to as Scope 3 emissions (McKinsey, 2024). Quantifying and managing Scope 3 emissions is not a widespread practice in HEROs (e.g., it is not done in the USM) and very relevant to HERO leadership given that are by far the largest source of GHG emissions in most organizations

(~90 percent) and therefore represent the largest opportunity for impact on mitigation of climate change (McKinsey, 2024; CDP, 2022). In addition to this, HEROs typically do not pursue other environmental footprint reductions such as land and water. Thus, two major emerging pain points that HERO leadership face in tackling sustainability are: (i) *addressing the magnitude of their environmental footprint with respect to Scope 3 GHG emissions and* (ii) *expanding their efforts towards sustainable supply chains to include the broader footprint of environmental inputs beyond carbon (e.g., land and water)*.

Unique Value Proposition

To address this problem, information and analytical tools are needed to prioritize policies and infrastructure investments in environmental footprint management so that they provide the best ROI possible in terms of costs and environmental effectiveness. A comprehensive *mapping* and *prioritization* of environmental footprint reduction opportunities for the USM's 15 HEROs, encompassing not only Scope 3 GHG emissions (*virtual carbon*) but also *virtual land* and *virtual water* will position the USM at the forefront of environmental stewardship globally within university systems. The solution developed and implemented for the USM will have broader applicability to other university systems around the world as well as companies and organizations in other sectors. This solution will allow these organizations' abilities to meet their strategic goals (like the USM case), achieve other CSR/ESG goals, and accelerate their progress towards circular economies.

Solution

The proposed solution combines incremental innovation of services (Tidd & Bessant, 2025) with technological/scientific innovation that expands the scope of existing product(s). The solution builds on existing AI products that quantify Scope 3 emissions (virtual carbon) in the supply chain of an organization (Loopily, CO2AI, Climatiq, Watershed) and incorporates additional capabilities to identify and calculate the magnitude of virtual land and virtual water in the supply chain. Three key features of this solution are as follows:

- It builds on existing/demonstrable AI products for assessment of Scope 3 emissions, enabling incremental innovation (e.g., Meta, 2025; Climate Leaders Coalition, 2025; BIS Innovation Hub, 2025).
- It expands the technology in this solution to identify and quantify the environmental footprint of the organizations' supply chain using virtual land and virtual water modeling (EEIO: Environmental-Extended Input-Output). No commercial products exist for this.
- Using carbon/land/water pricing methods (EEIO), it provides a calculation of ROI for policy and infrastructure investments to manage environmental footprint.

This solution would allow to embed environmental criteria (carbon/land/water) into purchasing processes, tools and decisions, minimizing footprint associated with acquisition of goods and services by HEROs, maintaining or increasing ROI of policy and infrastructure investments, and enabling a sustainable market transformation across university systems globally.

Scaling Strategy

Terra HEROs will grow through an intentional phased strategy that expands its target markets, strengthens operational capacity, and advances technological innovation. Early growth focuses on adoption within the USM, using this anchor market to refine the AI engine, standardize data integration processes, and demonstrate clear value through improved Scope 3 emissions insights (McKinsey, 2024). As the platform proves its effectiveness, the venture expands to regional partners, e.g., community colleges, state agencies, and neighboring university systems, before entering national higher education networks and other public-sector institutions with large procurement footprints. Operationally, the venture evolves from a small, centralized team to a scalable service model supported by automated onboarding tools, modular workflows, and dedicated units for analytics, client support, and vendor engagement (e.g., PlanetForward, CO2AI, DitchCarbon). Technologically, *Terra HEROs* progresses from basic natural language processing (NLP) and machine-learning classification models to advanced predictive analytics, decision-support systems, digital supply-chain twins, and generative AI capabilities that enable scenario testing and optimized procurement strategies (Deloitte, 2024). Together, these market, operational, and technological pathways create a growth engine that allows *Terra HEROs* to expand its user base, increase impact, and remain at the cutting edge of sustainability innovation.

Sustainable Growth Plan

Terra HEROs generates revenue through a diversified model that evolves as the venture scales, as shown in Table 6-6. In its early years (1-2), the venture will be bootstrapped by

UMCES (USM's Environmental University). Complementing this core stream, *Terra HEROs* secures competitive grants and sponsored research funding to support innovation in AI, sustainability analytics, and procurement systems. As it expands regionally and nationally, subscription revenue grows significantly with the onboarding of additional universities, state agencies, and research organizations. Leveraging its education infrastructure, the venture develops professional education and credentialing programs, offering training for procurement officers, sustainability staff, and students. As the platform matures technologically, *Terra HEROs* introduces vendor licensing opportunities for AI modules, data taxonomies, and emissions/footprint optimization tools, allowing for scalable revenue. By Year 5 and beyond, the revenue model stabilizes with a mature mix of earned income (subscriptions, licensing, vendor services, and education) reducing reliance on early-stage grants and creating a resilient financial structure capable of sustaining long-term innovation and impact.

Table 6-6: Growth Plan for Terra HEROs Years 1-5 *(source: prepared for this research)*

Budget Category	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Revenues					
UMCES Seed Funding	$400,000	$250,000	$200,000	$150,000	$100,000
Service Subscriptions	$0	$100,000	$300,000	$500,000	$800,000
Grants & Sponsored Research	$0	$200,000	$200,000	$200,000	$200,000
Vendor Partnerships	$0	$100,000	$200,000	$300,000	$500,000
Professional Education & Training	$0	$75,000	$150,000	$250,000	$300,000

Budget Category	Year 1	Year 2	Year 3	Year 4	Year 5
Total Revenue	**$400,000**	**$725,000**	**$1,050,000**	**$1,400,000**	**$1,900,000**
Expenses					
Personnel	$200,000	$350,000	$400,000	$450,000	$550,000
Platform Development & Maintenance	$50,000	$100,000	$150,000	$150,000	$250,000
Cloud Infrastructure & Security	$50,000	$50,000	$100,000	$150,000	$200,000
Administration & Operations	$50,000	$100,000	$150,000	$200,000	$250,000
Marketing, Travel, Partnerships	$50,000	$100,000	$150,000	$200,000	$250,000
Total Expenses	**$400,000**	**$700,000**	**$900,000**	**$1,150,000**	**$1,500,000**
Net Position	**$0**	**$25,000**	**$150,000**	**$250,000**	**$400,000**

Risk and Resilience

Terra HEROs faces several growth-related risks, particularly around data governance, customer adoption, and financial or technological stagnation, but its strategy addresses these proactively. The venture mitigates data-related risks through formal data-sharing agreements, strong cybersecurity practices, and transparent AI validation processes that build user trust. To ensure customers not only adopt but actively use the platform, *Terra HEROs* embeds change-management support, creates clear onboarding pathways, and defines quick-win use cases (USM and institutions in the SUNY system are lined up) that demonstrate immediate value. Financial and innovation risks are managed by diversifying revenue streams, e.g., subscriptions, vendor services, training, and grants, and by dedicating resources to continual platform improvement. Together, these strategies create a risk-aware, resilient operational model that protects *Terra HEROs*' credibility and sustainability as it scales.

Growth Metrics

Terra HEROs will measure its success through clear, actionable indicators that reflect both growth and impact (e.g., AASHE, 2025; Borchardt et al. 2025). Key metrics include: (i) increased customer adoption and renewal rates, demonstrating that campuses, agencies, companies and other organizations find lasting value in the platform; (ii) improved Scope 3 analytics coverage and accuracy, ensuring the AI engine reliably classifies procurement data and delivers high-quality insights; and (iii) tracking the cumulative reduction in carbon/water/land footprint addressed through *Terra HEROs*-supported interventions, showing real progress in reducing environmental impacts. Together, these indicators provide a concise, meaningful picture of how *Terra HEROs* expands its reach, strengthens its technology, and drives measurable sustainability outcomes.

Conclusion and Reflection

Terra HEROs' scaling plan supports future growth by expanding gradually across product users and markets while building a financially resilient and operationally efficient foundation. The venture grows first within USM, then to regional partners, and eventually nationally, ensuring that each phase strengthens and diversifies revenue generation and customer base. Simultaneously, operations evolve from a lean pilot structure to a standardized, scalable service model supported by continuous user-centric product development, modular workflows, and efficient data pipelines that keep costs stable as demand increases. Technological enhancements follow a staged innovation roadmap, improving performance and customer value without overextending resources. By pairing controlled market expansion with disciplined financial management, streamlined operations, and continuous improvement, *Terra HEROs* ensures it can scale responsibly while remaining both economically sustainable and organizationally strong.

CHAPTER 7

CONCLUSIONS, CONTRIBUTIONS AND IMPLICATIONS

7.1 Overview

This chapter concludes the dissertation by synthesizing the study's findings and articulating their significance for theory, practice, and policy. Building on the System Dynamics (SD) modeling framework, the overall modeling results and discussion, and the empirical case study application to the USM, the chapter highlights the research's core contributions, discusses managerial and policy implications for higher education leaders, acknowledges limitations, and outlines directions for future research. The chapter also consolidates the study's practical value by offering targeted recommendations for USM as a public university system operating within a complex and dynamic institutional environment.

7.2 Summary of Key Findings

This dissertation set out to examine how higher education institutions (HEROs) in the United States and internationally can effectively advance environmental sustainability through organizational change, strategic management, dynamic capabilities, and innovation and entrepreneurship. Responding to persistent gaps between sustainability aspirations and implementation outcomes, the study adopted a System Dynamics (SD) approach to model sustainability transformation as a dynamic, feedback-driven organizational process rather than a linear sequence of initiatives. The results demonstrate that sustainability transformation in HEROs is fundamentally path dependent and structurally conditioned. Incremental progress can occur under baseline conditions, but sustained transformation requires deliberate intervention at key leverage points. Across all policy scenarios, the findings reveal that reinforcing feedback loops linking governance, capabilities, innovation, and legitimacy are decisive in shaping long-term outcomes. Institutions that strengthen these loops achieve qualitatively different trajectories from those that rely on isolated projects or short-term interventions.

Governance and strategic integration emerge as foundational drivers of sustainability transformation. By stabilizing commitment, reducing strategic decay, and improving the conversion of intent into investment, governance reforms create the institutional conditions necessary for capability development and innovation to flourish. Dynamic capability building enables faster translation of sustainability commitments into action, particularly in the short to medium term, but proves insufficient on its own without durable governance anchoring. Organizational change and cultural alignment reduce resistance and enable diffusion across institutional domains, while sustainability innovation ecosystems amplify performance and visibility when embedded within coherent institutional systems. Finally, contextual differences between U.S. and international HEROs significantly influence both the speed and robustness of transformation, underscoring the importance of context-sensitive sustainability strategies.

Collectively, these findings support the central conclusion of this dissertation: environmental sustainability in higher education is not primarily a technical or project management challenge, but an organizational capability challenge shaped by feedback, timing, and institutional context. By integrating theory with simulation-based analysis, the study advances understanding of why sustainability leadership emerges in some institutions and not others, despite similar external pressures and stated commitments.

This research demonstrates that environmental sustainability in higher education institutions is best understood as a long-term organizational transformation process driven by interacting feedback mechanisms rather than by isolated initiatives. The System Dynamics simulations show that no single policy lever—governance reform, capability building, cultural change, or innovation acceleration—is sufficient on its own to generate sustained, system-wide sustainability performance. Instead, durable progress emerges when multiple reinforcing loops are activated simultaneously and sequenced appropriately.

Across the five policy scenarios, governance and strategy integration provide stability and reduce strategic decay; dynamic capabilities enable execution and accelerate performance gains; organizational change and culture reduce resistance and enhance resilience; and sustainability innovation ecosystems amplify impact and legitimacy. Institutional context, particularly the U.S. public higher education environment, conditions the speed, volatility, and durability of these dynamics. The case study application illustrates how these insights can be operationalized in a real-world multi-campus system.

7.3 Contributions to Research and Theory

This dissertation makes several contributions to the literature on sustainability, strategic management, and higher education. First, it advances theoretical integration by combining dynamic capabilities theory, organizational change, sustainability transitions, and innovation and entrepreneurship within a unified System Dynamics framework. This integration responds to calls for more process-oriented and temporally explicit theories of sustainability transformation in organizations. Second, the research contributes methodologically by demonstrating how SD modeling can be used as a rigorous, theory-informed approach for studying sustainability strategy in complex, decentralized organizations such as universities. The use of STARS data as a calibration and validation anchor further illustrates how qualitative and quantitative evidence can be combined in sustainability research. Third, the dissertation contributes to the higher education sustainability literature by moving beyond descriptive case studies toward a dynamic, comparative analysis of policy interventions. The scenario-based approach clarifies why similar sustainability initiatives can produce divergent outcomes across institutions and over time.

One of the central theoretical contributions of this dissertation lies in its extension of dynamic capabilities theory (DCT) into the domain of higher education sustainability. While DCT has been widely applied in corporate strategy research, only in recent years has it begun to emerge as a relevant framework for understanding the transformation of public and nonprofit organizations, including HEROs (Gohr et al., 2023; Guerrero, 2024). Existing studies show that universities, like firms, must develop sensing, seizing, and reconfiguring capabilities to adapt to technological disruption, funding shifts, and evolving societal expectations. However, empirical applications of DCT to sustainability transitions in HEROs remain sparse. This dissertation advances the literature by conceptualizing sustainability transformation as a dynamic capability process and by identifying the microfoundations—leadership behaviors, cross-functional collaboration, knowledge-sharing routines, and adaptive governance structures—that enable HEROs to respond effectively to sustainability imperatives.

A second theoretical contribution emerges through the integration of strategic sustainability and the NRBV with DCT. Recent scholarship argues that sustainability strategies increasingly serve as sources of differentiation for universities, influencing their global rankings, research competitiveness, student recruitment, and donor funding (Fernandez & Nagesh, 2023; Roy et al., 2022). Yet, the strategic management literature in higher education lacks a nuanced explanation of how sustainability strategies become operationalized and embedded within institutions. By linking NRBV (which explains why HEROs pursue sustainability for strategic purposes) with DCT (which explains how they build the capabilities necessary to implement sustainability), the dissertation builds a bridge between two previously disconnected literatures. This contributes to a more complete and dynamic understanding of strategic sustainability in HEROs.

A third contribution concerns the application of organizational change theory to sustainability transitions in universities. Recent research indicates that sustainability-related change in HEROs requires shifts not only in policy and strategy but also in culture, identity, and distributed leadership practices (Schein, 2010; Rieg et al., 2021; Marshall et al., 2023). By empirically examining the mediating role of organizational change processes between sustainability strategies and institutional performance, the study enriches existing change models and extends them into the sustainability domain. It also illustrates how cross-unit coordination, participatory governance, and values-driven leadership shape the emergence of dynamic capabilities.

The dissertation also contributes to entrepreneurial university and innovation ecosystem theory, which has evolved significantly in the last five years to incorporate sustainability and social impact as core dimensions of university entrepreneurship (Meek et al., 2023; Dote-Pardo et al., 2025). By analyzing how sustainability strategies and dynamic capabilities influence sustainability-driven innovation and entrepreneurship, the study advances theoretical debates about the role of universities as agents of societal change. It highlights how HEROs function not merely as educational and research organizations but as orchestrators of sustainability-oriented innovation ecosystems involving industry, government, civil society, and communities.

Finally, the study offers a new integrated conceptual framework that synthesizes institutional pressures, strategic sustainability, dynamic capabilities, organizational change, and innovation ecosystem perspectives. This integrative model addresses one of the major gaps in the literature: the lack of comprehensive frameworks capable of explaining multi-level, cross-functional, and contextually variable sustainability transformations in HEROs (Giovannoni & Fabietti, 2022; Neudert et al., 2024). The model is expected to serve as a foundation for future theoretical development and empirical testing in the field.

7.4 Practical Contributions

From a practical standpoint, the dissertation offers significant contributions for university leaders, sustainability professionals, and institutional decision-makers seeking to advance sustainability transformation. First, the study will produce a diagnostic framework for assessing institutional sustainability capabilities, drawing from dynamic capabilities constructs tailored to the higher education context. This framework will enable HEROs to evaluate their strengths and weaknesses across sensing, seizing, and reconfiguring dimensions, offering actionable insights for capability development. Recent literature identifies the need for universities to articulate clearer roadmaps for sustainability transformation; however, few tools exist to support diagnostic assessment at this level of sophistication (Leal Filho et al., 2022; Gunnlaugsson & Þórhallsson, 2021). This study responds directly to this gap.

Second, the findings are expected to inform leadership and governance practices. Research consistently shows that sustainability efforts in HEROs succeed only when leadership commitment is paired with distributed governance, faculty engagement, and cross-unit collaboration (Giovannoni & Fabietti, 2022; Marshall et al., 2023). By identifying specific leadership behaviors and governance structures that facilitate dynamic capability development, this study offers practical guidance for provosts, presidents, deans, and sustainability officers seeking to mobilize and sustain momentum around sustainability initiatives.

Third, the dissertation contributes to the operational side of sustainability by illustrating how HEROs can reconfigure their organizational structures and processes to embed sustainability in academic programs, research agendas, operations, and community partnerships. Insights derived from the qualitative phase are expected to highlight best practices for integrating sustainability across teaching, research, and campus operations, an area where recent studies call for more systematic guidance (Trevisan et al., 2024).

Fourth, the study enhances understanding of innovation and entrepreneurship practices centered on sustainability. The results will offer evidence-based guidance for universities seeking to expand their sustainability-oriented innovation ecosystems through incubators, living labs, community-based partnerships, and collaborative research networks. As sustainability innovation gains traction globally, HEROs increasingly need strategies to leverage their assets for regional and global impact (Nguyen et al., 2025; Neudert et al., 2024). This dissertation provides empirically grounded insights into how institutions can strengthen these roles.

7.5 Methodological Contributions

This research contributes to theory in several important ways. First, it extends dynamic capabilities theory by explicitly modeling capabilities as accumulating stocks subject to erosion, delay, and interaction with governance and culture. This dynamic representation moves beyond static or cross-sectional conceptualizations and demonstrates how capabilities must be continually renewed to sustain sustainability-driven advantage.

Second, the study advances sustainability transitions scholarship by embedding organizational change processes within a formal feedback framework. Rather than treating sustainability as an exogenous goal or normative imperative, the SD model reveals how sustainability outcomes emerge endogenously from interactions among strategy, learning, resistance, and legitimacy. This approach helps reconcile disparate findings in the higher education sustainability literature by showing how similar interventions can produce divergent outcomes depending on system structure and timing.

Third, the dissertation contributes to higher education research by offering an integrated explanation of the entrepreneurial and sustainability-oriented university. The results demonstrate that innovation and entrepreneurship for sustainability are not isolated functions, but outcomes of broader institutional systems shaped by governance, culture, and capability development. This insight bridges literatures on the entrepreneurial university, institutional theory, and sustainability management.

7.6 Policy and Societal Contributions

Beyond scholarly and institutional impacts, the dissertation also aims to contribute to broader sustainability policy and societal change. HEROs occupy a critical position within national and global sustainability frameworks. As major employers, landholders, knowledge producers, and educational institutions, universities have the potential to accelerate progress toward the United Nations Sustainable Development Goals (SDGs). Yet, recent analyses show wide variation in the extent to which HEROs contribute to (or lag behind) SDG implementation (Salvia et al., 2019; Leal Filho et al., 2023).

This study contributes to policy debates by identifying the institutional conditions and policy environments that most effectively support sustainability transformation. The cross-national design offers insights into how different funding regimes, accreditation processes, and regulatory frameworks influence HERO sustainability performance. These findings may be relevant to policymakers in education ministries, accreditation agencies, and sustainability consortia seeking to design policies that foster institutional commitment and cross-sectoral collaboration.

At the societal level, the research highlights the role of HEROs as anchor institutions in sustainability transitions. Recent literature suggests that universities increasingly serve as hubs for community engagement, sustainable economic development, and workforce development in the green economy (Neudert et al., 2024; Dote-Pardo et al., 2025). By examining how sustainability-driven innovation ecosystems emerge within and around HEROs, the dissertation offers insights into how universities can more effectively support societal resilience and climate adaptation.

7.7 Managerial and Policy Implications

The findings offer several practical implications for university leaders and policymakers. First, sustainability strategies should prioritize institutionalization over proliferation. Governance integration, accountability mechanisms, and long-term strategic anchoring are more effective than expanding portfolios of disconnected initiatives. Second, investments in dynamic capabilities, such as data systems, cross-functional teams, and adaptive planning, can accelerate early progress but should be embedded within stable governance structures to avoid fragility. Third, organizational change and culture should be treated as ongoing managerial responsibilities rather than temporary interventions, particularly in institutions characterized by shared governance and professional autonomy.

For policymakers and sustainability networks, the results suggest that performance frameworks and rankings, including STARS, are most effective when they reinforce learning and legitimacy rather than compliance. Incentives that reward institutional coherence, continuity, and long-term capability development are likely to produce more durable sustainability outcomes than short-term project funding alone. For senior leaders and governing boards, the findings underscore that sustainability should be managed as a portfolio of reinforcing strategies rather than as a collection of standalone projects.

Governance mechanisms that institutionalize sustainability priorities are essential for stability, but they must be complemented by investments in capabilities, culture, and innovation to achieve scale and impact.

From a policy perspective, the results suggest that public accountability frameworks and state-level climate policies can be more effective when they recognize institutional dynamics and allow for adaptive implementation pathways. Policymakers should focus not only on targets and reporting, but also on enabling learning, coordination, and innovation across institutions. For business school audiences, the research demonstrates the relevance of strategic management concepts, such as dynamic capabilities and feedback-driven performance, to sustainability challenges in non-market and public-sector contexts.

7.8 Policy Recommendations for the University System of Maryland

Building on the gap analysis comparing current practices at the USM with the idealized policy scenario archetypes, this subsection outlines targeted policy recommendations designed to close identified gaps while respecting the system's governance structure, institutional diversity, and public accountability context. The recommendations emphasize alignment, sequencing, and leverage rather than the introduction of entirely new initiatives.

Strengthen formal governance integration to reduce strategic fragmentation. The gap analysis reveals that while sustainability is articulated in system plans and aligned with state policy, it is not yet fully institutionalized as a binding criterion across budgeting, capital planning, and performance management. USM should therefore formalize sustainability governance by embedding sustainability metrics into system-level dashboards, capital approval processes, and executive accountability mechanisms. This recommendation directly addresses Scenario 1 gaps by reducing strategic decay and ensuring continuity across leadership transitions, a critical need in the U.S. public higher education context.

Invest in shared system-wide dynamic capabilities to accelerate execution and diffusion. USM's uneven distribution of sustainability capabilities across campuses represents a major constraint on system-wide performance. Rather than relying on isolated campus-level investments, USM should prioritize shared data platforms, analytics, training programs, and communities of practice. These system-coordinated investments would reduce duplication, shorten learning delays, and enable lower-capacity campuses to benefit from system expertise. This recommendation responds directly to Scenario 2 gaps by shifting capability development from a fragmented to a coordinated model.

Prioritize organizational change and cultural alignment as an enabling condition, not an ancillary activity. The analysis indicates broad rhetorical support for sustainability but inconsistent translation into everyday decision-making. USM should therefore elevate change management, engagement, and sensemaking as explicit components of its sustainability strategy. Policies should support faculty, staff, and student engagement initiatives that connect sustainability to academic quality, operational excellence, and public service. This recommendation addresses Scenario 3 gaps by reducing resistance, smoothing implementation, and increasing resilience to external shocks.

Coordinate and scale sustainability innovation ecosystems at the system level. USM exhibits strong but localized sustainability innovation activity concentrated at select campuses. To close Scenario 4 gaps, the system should establish coordination mechanisms, such as shared challenge funds, cross-campus innovation networks, and aligned external partnerships that allow innovation to scale and diffuse. This approach leverages USM's multi-campus structure as a strategic asset rather than a coordination burden, amplifying both impact and visibility.

Adopt a context-sensitive, sequenced implementation strategy. Finally, consistent with Scenario 5 insights, USM should avoid one-size-fits-all mandates and instead adopt a sequenced portfolio approach. Governance integration and cultural alignment should be prioritized early to stabilize the system, followed by coordinated capability building and ecosystem scaling. This sequencing reduces volatility, manages risk, and maximizes long-term returns on sustainability investments.

Collectively, these recommendations suggest that USM's primary opportunity lies not in increasing ambition, but in strategically aligning, sequencing, and reinforcing existing efforts. By closing the gaps identified in this analysis, USM can accelerate sustainability performance while enhancing stability, equity, and public trust across the system.

7.9 Limitations of this Research

Despite its contributions, this study has several limitations that should be acknowledged. First, System Dynamics models necessarily simplify reality. While the model captures key feedback structures and dynamics, it cannot represent all institutional nuances, stakeholder conflicts, or contextual contingencies that influence sustainability outcomes in practice.
Second, the calibration relies on AASHE STARS data, which are self-reported and may vary in completeness and interpretation across institutions and over time. Although the

model treats STARS indicators as proxies rather than direct measures of organizational capabilities, data limitations may affect calibration precision. The model emphasizes behavioral realism over numerical accuracy, but results should be interpreted as illustrative of patterns rather than precise forecasts.

Third, the policy scenarios are stylized representations of real-world interventions. Actual governance reforms, capability-building programs, and innovation ecosystems differ in scope, quality, and political feasibility. While the scenarios capture core mechanisms, real-world implementation may produce additional dynamics not represented in the model.

Fourth, the case study application focuses on a single public university system. While USM provides a rich and relevant context, the findings may not generalize fully to private institutions or systems operating under substantially different governance regimes.

Finally, the study focuses primarily on institutional-level dynamics and does not explicitly model broader political, economic, or societal shocks beyond generalized exogenous disturbances. These external forces may significantly influence sustainability trajectories in ways not fully captured here.

7.10 Future Research Directions

This dissertation opens several promising avenues for future research. First, empirical studies could integrate SD modeling with qualitative case studies or longitudinal mixed methods designs to deepen understanding of how governance and capability interventions unfold in practice. Combining simulation with ethnographic or interview-based insights would enrich both theoretical and practical understanding.

Second, future research could extend the model to incorporate multi-level dynamics, explicitly linking institutional sustainability transformation to regional, national, or global sustainability systems. This would allow exploration of how universities interact with policy regimes, industry partners, and community stakeholders as part of broader sustainability transitions. Third, researchers could adapt the model to explore equity, justice, and inclusion dimensions of sustainability, examining how different governance and capability configurations affect the distribution of benefits and burdens within institutions and communities. Fourth, comparative research could further refine contextual regimes by incorporating institutional typologies, funding models, and governance traditions across countries and regions. Such work would strengthen the generalizability and policy relevance of SD-based sustainability research in higher education.

Finally, future studies could experiment with participatory System Dynamics approaches, engaging university leaders, faculty, students, and external stakeholders in co-developing and testing models. This approach would enhance learning, legitimacy, and practical impact while advancing methodological innovation. This dissertation demonstrates the value of System Dynamics as a powerful methodological lens for understanding sustainability transformation in higher education. By revealing the feedback structures and long-term consequences of strategic choices, the study provides both theoretical insight and practical guidance for institutions seeking to move from aspiration to action. Ultimately, the findings reinforce a central message: achieving environmental sustainability in higher education requires sustained organizational learning, strategic coherence, and an appreciation of time, feedback, and context.

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APPENDIX A

SYSTEM DYNAMICS MODEL FORMULATION AND CODE

The System Dynamics model developed for this dissertation is documented here through its formulation (causal loop diagram) and model equations (model code). The causal loop diagram (CLD) is composed of core system variables, reinforcing loops and balancing loops. These components of the CLD are highlighted below and illustrated in Figure A-1.

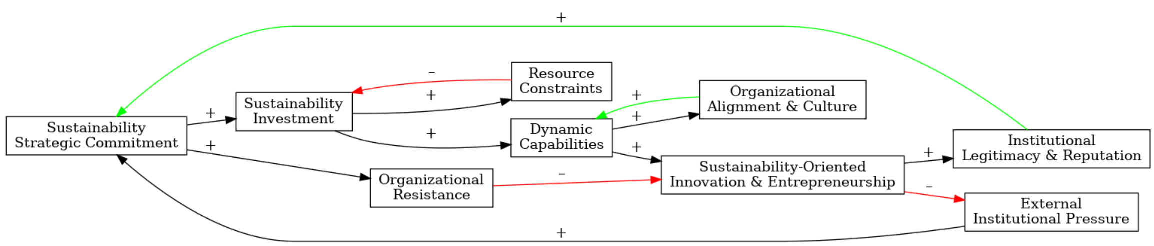

***Figure A-1**: Causal Loop Diagram for HEROES System Dynamics Model*

Core System Variables

- Sustainability Strategic Commitment
- Sustainability Investment (financial, human, symbolic)
- Dynamic Capabilities (Sensing, Seizing, Reconfiguring)
- Organizational Alignment & Culture
- Sustainability-Oriented Innovation & Entrepreneurship
- Institutional Legitimacy & Reputation
- External Institutional Pressure
- Resource Constraints
- Organizational Resistance / Inertia

Reinforcing Loops (R)

R1: Strategy–Capability–Innovation Loop (Core Growth Engine): As universities invest in sustainability, they build capabilities that generate innovation and visible outcomes. These outcomes increase legitimacy, reinforcing leadership commitment and future investment.

Sustainability Strategy → Investment → Dynamic Capabilities → Innovation → Legitimacy → Sustainability Strategy

Sustainability Strategic Commitment

→ (+) Sustainability Investment

→ (+) Dynamic Capabilities

→ (+) Sustainability-Oriented Innovation & Entrepreneurship

→ (+) Institutional Performance & Visibility

→ (+) Institutional Legitimacy & Reputation

→ (+) Sustainability Strategic Commitment

R2: Learning and Organizational Alignment Loop: Capability development improves coordination and shared understanding, which in turn accelerates further capability accumulation.

Dynamic Capabilities → Organizational Learning → Organizational Alignment → Implementation Effectiveness → Dynamic Capabilities

Dynamic Capabilities

→ (+) Organizational Learning & Cross-Unit Collaboration

→ (+) Organizational Alignment & Culture

→ (+) Effectiveness of Sustainability Implementation

→ (+) Dynamic Capabilities

R3: Innovation Ecosystem Loop (Entrepreneurial University): Universities that build sustainability capabilities become more attractive partners, reinforcing innovation capacity and resource inflows.

Dynamic Capabilities → External Partnerships → Sustainability Innovation → External Support → Sustainability Investment

Dynamic Capabilities

→ (+) External Partnerships & Innovation Ecosystem Engagement

→ (+) Sustainability-Oriented Innovation & Entrepreneurship

→ (+) External Funding & Stakeholder Support

→ (+) Sustainability Investment

R4: External Pressure–Response Loop: As institutions respond successfully to external demands, pressure diminishes, stabilizing the system.

External Institutional Pressure

→ (+) Sustainability Strategic Commitment

→ (+) Sustainability Investment

→ (+) Observable Sustainability Outcomes

→ (–) Perceived External Pressure

Balancing Loops (B)

B1: Resource Constraint Loop: Limited budgets, staff capacity, and attention constrain how fast sustainability initiatives can scale.

Sustainability Investment → Resource Use → Resource Constraints → Sustainability Investment

Sustainability Investment

→ (+) Resource Utilization

→ (+) Resource Constraints

→ (–) Ability to Increase Sustainability Investment

B2: Organizational Resistance Loop: Cultural inertia, silos, and competing priorities slow or dilute sustainability efforts.

Strategic Commitment → Change Initiatives → Organizational Resistance → Implementation Effectiveness

Sustainability Strategic Commitment

→ (+) Change Initiatives

→ (+) Organizational Resistance / Inertia

→ (–) Implementation Effectiveness

→ (–) Sustainability Outcomes

B3: Leadership Turnover Loop: Leadership changes disrupt long-term sustainability trajectories.

B3: Leadership Turnover → Strategic Continuity → Sustainability Strategic Commitment

Leadership Turnover

→ (–) Strategic Continuity

→ (–) Sustainability Strategic Commitment

→ (–) Sustainability Investment

Modeling Code

Time unit: Year

Stock scale: 0–100 (index)

```
*************************************************
** STOCKS (LEVELS)
*************************************************


Sustainability_Strategic_Commitment =
  INTEG( Strategy_Reinforcement - Commitment_Decay ,
        SSC_Initial )  ~~|  Index (0-100)


Dynamic_Capabilities =
  INTEG( Capability_Development - Capability_Erosion ,
        DC_Initial )  ~~|  Index (0-100)


Organizational_Alignment_Culture =
  INTEG( Cultural_Alignment_Rate - Cultural_Drift ,
```

```
        OAC_Initial ) ~~|  Index (0-100)


Sust_Innovation_Entrepreneurship =
  INTEG( Innovation_Generation_Rate - Innovation_Obsolescence ,
        SIE_Initial ) ~~|  Index (0-100)


Institutional_Legitimacy_Reputation =
  INTEG( Legitimacy_Accumulation - Legitimacy_Loss ,
        ILR_Initial ) ~~|  Index (0-100)



****************************************************
** FLOWS (RATES)
****************************************************


Strategy_Reinforcement =
  Strategy_Reinforcement_Rate
  * (100 - Sustainability_Strategic_Commitment)/100
  * (1 + Strategy_Legitimacy_Elasticity * Institutional_Legitimacy_Reputation/100)
  * (1 + Pressure_to_Strategy_Elasticity * External_Institutional_Pressure/100)
  * (1 - Leadership_Disruption_Factor)
  ~~|  Index/Year
```

Commitment_Decay =

Commitment_Decay_Rate

* Sustainability_Strategic_Commitment

* (1 + Leadership_Disruption_Factor)

~~| Index/Year

Capability_Development =

Capability_Build_Rate

* Sustainability_Investment/100

* Sustainability_Strategic_Commitment/100

* (1 - Resource_Constraints/100)

* (1 - Capability_Build_Resistance_Effect * Organizational_Resistance/100)

* (100 - Dynamic_Capabilities)/100

~~| Index/Year

Capability_Erosion =

Capability_Erosion_Rate

* Dynamic_Capabilities

~~| Index/Year

Cultural_Alignment_Rate =

Alignment_Build_Rate

* Dynamic_Capabilities/100

* Sustainability_Strategic_Commitment/100

* (1 - Resource_Constraints/100)

* (100 - Organizational_Alignment_Culture)/100

~~| Index/Year

Cultural_Drift =

Cultural_Drift_Rate

* Organizational_Alignment_Culture

* (1 + Shock_Factor)

~~| Index/Year

Innovation_Generation_Rate =

Innovation_Productivity_Rate

* Dynamic_Capabilities/100

* Organizational_Alignment_Culture/100

* Sustainability_Investment/100

* (1 - Organizational_Resistance/100)

* Innovation_Delay_Effect

* (100 - Sust_Innovation_Entrepreneurship)/100

~~| Index/Year

Innovation_Obsolescence =

Innovation_Obsolescence_Rate

* Sust_Innovation_Entrepreneurship

~~| Index/Year

Legitimacy_Accumulation =

Legitimacy_Gain_Rate

* Sust_Innovation_Entrepreneurship/100

* (1 + Visibility_Amplifier * Sustainability_Investment/100)

* (100 - Institutional_Legitimacy_Reputation)/100

~~| Index/Year

Legitimacy_Loss =

Legitimacy_Loss_Rate

* Institutional_Legitimacy_Reputation

* (1 + Greenwash_Penalty_Factor)

~~| Index/Year

****

** AUXILIARIES

****

Sustainability_Investment =

MIN(100,

Base_Investment

+ Investment_from_Strategy * Sustainability_Strategic_Commitment/100

+ Investment_from_Legitimacy * Institutional_Legitimacy_Reputation/100

+ Investment_from_Pressure * External_Institutional_Pressure/100

)

* (1 - Resource_Constraints/100)

~~| Index (0-100)

External_Institutional_Pressure =

MAX(0,

Baseline_Pressure

+ Pressure_from_Gaps * (Target_Sustainability -

Sust_Innovation_Entrepreneurship)/100

- Pressure_Reduction_from_Outcomes * Sust_Innovation_Entrepreneurship/100

)

~~| Index (0-100)

Resource_Constraints =

MIN(100,

```
    Resource_Constraint_Sensitivity
    * MAX(0, Sustainability_Investment - Resource_Capacity)/100
    + Constraint_from_Shocks * Shock_Factor
 )
 ~~| Index (0-100)


Organizational_Resistance =
 MIN( 100,
    Resistance_Base
    + Resistance_from_Misalignment * (100 - Organizational_Alignment_Culture)/100
    + Resistance_from_Change_Speed *
ABS(Strategy_Reinforcement)/Max_Expected_Change
    - Resistance_Reduction_from_Capabilities * Dynamic_Capabilities/100
 )
 ~~| Index (0-100)


**************************************************
** DELAYS / NONLINEAR EFFECTS
**************************************************


Innovation_Delay_Effect =
```

DELAY1(Dynamic_Capabilities/100, Innovation_Delay_Time)

~~| Dimensionless (0-1)

****

** EXOGENOUS SHOCKS / STRUCTURAL FACTORS

****

Leadership_Disruption_Factor =

Leadership_Turnover_Rate

~~| Dimensionless (0-1)

Shock_Factor =

Exogenous_Shock_Level

~~| Dimensionless (0-1)

Greenwash_Penalty_Factor =

Greenwash_Sensitivity

* MAX(0, Sustainability_Strategic_Commitment -

Sust_Innovation_Entrepreneurship)/100

~~| Dimensionless (0-1)

```
***************************************************
** CONSTANTS / PARAMETERS (SET THESE)
***************************************************

SSC_Initial = 40 ~~| Index
DC_Initial  = 30 ~~| Index
OAC_Initial = 35 ~~| Index
SIE_Initial = 20 ~~| Index
ILR_Initial = 30 ~~| Index

Target_Sustainability = 80 ~~| Index
Resource_Capacity = 60 ~~| Index

Base_Investment = 10 ~~| Index
Investment_from_Strategy = 40 ~~| Index
Investment_from_Legitimacy = 15 ~~| Index
Investment_from_Pressure = 20 ~~| Index

Baseline_Pressure = 50 ~~| Index
Pressure_from_Gaps = 30 ~~| Index
Pressure_Reduction_from_Outcomes = 25 ~~| Index

Strategy_Reinforcement_Rate = 12 ~~| 1/Year
```

Commitment_Decay_Rate = 0.08 ~~| 1/Year

Capability_Build_Rate = 10 ~~| 1/Year

Capability_Erosion_Rate = 0.06 ~~| 1/Year

Capability_Build_Resistance_Effect = 0.6 ~~| Dimensionless

Alignment_Build_Rate = 8 ~~| 1/Year

Cultural_Drift_Rate = 0.05 ~~| 1/Year

Innovation_Productivity_Rate = 14 ~~| 1/Year

Innovation_Obsolescence_Rate = 0.10 ~~| 1/Year

Legitimacy_Gain_Rate = 10 ~~| 1/Year

Legitimacy_Loss_Rate = 0.07 ~~| 1/Year

Visibility_Amplifier = 0.5 ~~| Dimensionless

Strategy_Legitimacy_Elasticity = 0.4 ~~| Dimensionless

Pressure_to_Strategy_Elasticity = 0.3 ~~| Dimensionless

Resource_Constraint_Sensitivity = 120 ~~| Dimensionless

Constraint_from_Shocks = 30 ~~| Dimensionless

Resistance_Base = 10 ~~| Index

Resistance_from_Misalignment = 60 ~~| Dimensionless

Resistance_from_Change_Speed = 25 ~~| Dimensionless

Resistance_Reduction_from_Capabilities = 30 ~~| Dimensionless

Max_Expected_Change = 20 ~~| Index/Year

Innovation_Delay_Time = 2 ~~| Year

Leadership_Turnover_Rate = 0.05 ~~| Dimensionless (0-1)

Exogenous_Shock_Level = 0.00 ~~| Dimensionless (0-1)

Greenwash_Sensitivity = 0.4 ~~| Dimensionless

APPENDIX B

Model Calibration and Validation

1) Calibration Objective and Logic

The goal of calibration is not point prediction, but to ensure the SD model reproduces plausible trajectories of sustainability transformation and yields policy-relevant behavior consistent with observed STARS performance patterns across institutions over time. Calibration will focus on (a) aligning model stocks to observable STARS-derived indicators, (b) estimating parameters so simulated trajectories match empirical ranges and growth rates, and (c) validating model behavior under multiple scenarios and institutional archetypes.

2) STARS data extraction strategy

STARS provides institution-level, category-level, and (in many cases) credit-level scores. For calibration, the study will compile a dataset for a cohort of HEROs with:

- Multiple STARS submissions over time (preferred for dynamic calibration)
- Complete category scores (Academics, Engagement, Operations, Planning & Administration, Innovation & Leadership)

For each institution and submission year, extract:

- Overall STARS rating/score
- Category scores (and subcategory/credit scores where available)

- Submission date and reporting boundary notes (to control for reporting artifacts)

3) Mapping STARS measures to SD model constructs

Because SD stocks are latent "state variables," calibration requires constructing **proxies** from STARS categories/credits.

A. Sustainability-Oriented Innovation & Entrepreneurship (Stock: SIE)

Use STARS indicators most directly reflecting innovation, diffusion, and applied solutions:

- Innovation & Leadership category (core proxy)
- Relevant credits in Academics (research, curricular innovation) and Engagement (community partnerships) where available

  Construct:

  [

  SIE_index = w_1(I&L) + w_2(Academics_innovation_credits) + w_3(Engagement_partnership_credits)

  ]

B. Organizational Alignment & Culture (Stock: OAC)

Use STARS components reflecting institutionalization, incentives, and culture:

- Planning & Administration (especially governance/coordination, assessment, transparency, diversity/wellbeing where used as culture signals)

- Engagement credits related to sustainability culture/participation

  Construct:

  [

  OAC_index = v_1(P&A_{governance+assessment}) +

  v_2(Engagement_{culture}) + v_3(Reporting_consistency)

  ]

C. Sustainability Strategic Commitment (Stock: SSC)

Use STARS indicators representing formal strategy, commitments, and accountability:

- Planning & Administration credits tied to strategic planning, climate plans, targets, oversight mechanisms
- Any credits explicitly tied to commitments/targets/monitoring

  Construct:

  [

  SSC_index = u_1(P&A_{planning+targets}) +

  u_2(Assessment/Reporting_strength)

  ]

D. Institutional Legitimacy & Reputation (Stock: ILR)

STARS is itself a reputational signal, but to avoid circularity, use a **hybrid proxy**:

- STARS overall score (normalized) as a legitimacy component
- "Visibility/leadership" elements from Innovation & Leadership (narrative/leadership credits where present)

Construct:

[

ILR_index = r_1(STARS_{overall}) + r_2(I&L_{leadership/recognition})

]

E. Dynamic Capabilities (Stock: DC)

Dynamic capabilities are not directly reported in STARS. Calibrate DC as a **latent state** inferred from STARS patterns that reflect (i) breadth of action, (ii) rate of improvement, and (iii) cross-domain coordination:

- Cross-category balance (reduces "siloed sustainability")
- Rate of change in category scores between submissions
- Presence of planning/assessment mechanisms enabling learning

Construct (example):

[

DC_index = a_1(\Delta STARS_{overall}/\Delta t) + a_2(Balance_{categories})

+ a_3(P&A_{assessment})

]

Practical note: Weights (w, v, u, r, a) can be initially equal, then refined via sensitivity testing and expert review.

4) Normalization and time series preparation

- Convert all constructed indices to a consistent **0–100 scale**.
- Build a **panel dataset**: institution × submission year.

- Where institutions have irregular reporting intervals, compute annualized changes:

$$Annualized\ Change = (Score_{t2}-Score_{t1})/(t2-t1)$$

- Flag potential discontinuities (e.g., boundary changes, missing sections) and treat them as "reporting shocks" rather than real performance changes.

5) Parameter estimation approach

Use a staged calibration process:

Stage 1: Structural calibration (face validity)

- Confirm causal directions and loop behavior are consistent with the STARS construct mapping (e.g., improvements in Planning & Administration should plausibly precede broad improvements across categories).

Stage 2: Range calibration (cross-sectional)

- Fit initial parameter values so the model reproduces the cross-sectional distribution of STARS-based indices (e.g., typical SSC/OAC/SIE ranges for Bronze/Silver/Gold/Platinum institutions).

Stage 3: Dynamic calibration (longitudinal)

For HEROs with ≥2 submissions:

- Calibrate flow rates (capability build, alignment build, innovation generation, etc.) so simulated trajectories match observed **annualized improvement rates** in relevant indices.
- Use an error metric such as mean absolute percentage error (MAPE) on trajectories of SIE_index and SSC_index, plus a penalty for unrealistic oscillations.

Stage 4: Archetype calibration

Calibrate parameter sets for a small set of institutional archetypes:

- "High-commitment / low-capability" starters
- "Operations-strong / academics-weak"
- "Innovation hub / governance weak"
- "Resource constrained"

  This supports generalizability and policy testing.

6) Calibration of key feedback effects using STARS patterns

Use observable STARS relationships to tune nonlinearities:

- **Legitimacy → Strategy reinforcement:** institutions that move from Silver→Gold often show increased breadth/coordination; tune elasticity so legitimacy accelerates SSC growth.
- **Resource constraints:** institutions plateauing across submissions (little gain despite commitment) can inform constraint sensitivity.

- **Resistance/inertia:** uneven category performance (strong operations, weak academics/engagement) suggests internal barriers; tune resistance so it suppresses cross-domain diffusion.

7) Validation tests using STARS-derived evidence

After calibration, run standard SD validity tests tied to STARS evidence:

- **Behavior reproduction tests:** Can the model reproduce typical improvement trajectories (e.g., slow early gains, faster mid-stage, plateau near upper bound)?
- **Extreme condition tests:** If investment collapses, do STARS indices decay gradually (not instantly)?
- **Sensitivity analysis:** Identify parameters to which STARS trajectories are most sensitive (e.g., resistance, resource constraints, delay times).
- **Cross-validation:** Calibrate on one subset of institutions, validate behavior on another subset.

8) Linking policy scenarios to STARS outcomes

Define policy scenarios as parameter changes and report outcomes as projected changes in STARS-aligned indices over 5–15 years:

- Building a Center of Excellence (boost investment efficiency, reduce resistance)
- Leadership turnover (increase strategic decay and delay times)
- Budget constraint (increase resource constraint sensitivity)
- Strong external pressure (increase pressure-to-strategy elasticity)

9) Documentation and transparency

To ensure credibility:

- Document all STARS variables used, data transformations, index formulas, and weight choices.
- Provide a "data-to-construct crosswalk" table (STARS category/credit → stock proxy).
- Record assumptions about reporting gaps and boundary changes.