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AI-Driven Entrepreneurial Orientation and Sustainable Green Innovation Toward University Financial Sustainability Through Circular Economy Principles and Green Metrics for Self-Efficacy

Mohamed Nasr Saeed ^{1,*}  and Mossab Saud Alholiby ² ¹ Applied College, King Faisal University, Hofuf 31982, Al-Ahsa, Saudi Arabia² Department of Educational Leadership, College of Education, King Faisal University, Hofuf 31982, Al-Ahsa, Saudi Arabia; malholiby@kfu.edu.sa

* Correspondence: mnmsaid@kfu.edu.sa

Abstract

Universities worldwide face escalating financial pressures while simultaneously confronting demands to adopt sustainable practices. This study examines whether Sustainable Green Innovation (SGI) serves as the central transmission mechanism through which AI-Driven Entrepreneurial Orientation (AI-DEO) and Green Metrics for Self-Efficacy (GMSE) influence University Financial Sustainability (UFS) in higher education institutions, within the broader framework of Circular Economy Principles (CEP). Cross-sectional survey data were collected from 1279 faculty and staff members at King Faisal University (Saudi Arabia) and Benha University (Egypt) between October 2025 and January 2026. Regression-based structural path analysis with nonparametric bootstrapped mediation testing (5000 resamples) was employed to test four hypotheses. The results show that AI-DEO emerged as the dominant positive predictor of SGI ($\beta = 0.732$, $p < 0.001$), while GMSE did not show a statistically significant association with SGI once AI-DEO was included in the model ($\beta = -0.034$, $p = 0.246$). SGI emerged as the strongest predictor of UFS ($\beta = 0.369$, $p < 0.001$), supporting an innovation-mediated route to financial sustainability. The indirect effect of CEP on SGI through AI-DEO was statistically significant (indirect = 0.3473; 95% CI [0.3123, 0.3835]), supporting full mediation. Hypotheses H1, H2a, H2b, and H3 were supported; H4 was not supported. These findings indicate that financial resilience in universities is primarily innovation-mediated and orientation-driven. The study contributes to the sustainability-in-higher-education literature by clarifying SGI as a central transmission mechanism and highlighting the importance of building operational green competence alongside strategic AI-Driven entrepreneurial orientation.

Keywords: AI-driven; entrepreneurial orientation; circular economy; green metrics; self-efficacy; sustainable innovation; financial sustainability



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1. Introduction

The combination of entrepreneurship with environmental sustainability practices has received extensive research attention because environmental sustainability has become a vital global issue. The research investigates how Circular Economy Principles CEP, AI-Driven Entrepreneurial Orientation AI-DEO and Green Metrics Self-Efficacy GMSE affect Sustainable Green Innovation SGI development in higher education institutions. The process of maintaining university financial sustainability UFS becomes essential for universities because they face rising operational expenses and funding difficulties that

require green initiatives to be understood [1]. Entrepreneurs who practice AI-DEO adopt environmentally friendly business practices through a strategic mindset, which leads them to create sustainable business models by implementing innovative solutions and taking calculated risks [2].

The urgency of this challenge is amplified by the current global policy landscape. The United Nations Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education), SDG 8 (Decent Work and Economic Growth), and SDG 13 (Climate Action), explicitly call on higher education institutions to lead sustainability transformation [3]. At the regional level, Saudi Vision 2030 has established green economy development and knowledge diversification as national strategic priorities, directly incentivizing universities to embed circular economy principles into their operational and academic models [4]. Simultaneously, Egypt's Sustainable Development Strategy 2030 designates universities as key drivers of green innovation and economic diversification [5]. These policy frameworks have created an unprecedented institutional mandate for universities to integrate sustainability into their financial planning and innovation strategies.

The two concepts, AI-DEO and GMSE, establish a framework that shows universities SGI because they create an environment that supports eco-friendly practices. The research intends to examine how AI-DEO and GMSE help universities build SGI while also supporting their financial sustainability efforts. Universities improve their operations by adopting green innovations while they draw environmentally friendly students and staff members who will create additional income opportunities for the institution. The research investigates how universities that commit to sustainability achieve economic success while showing that environmental protection and financial prosperity should work together to benefit higher education institutions.

From an economic perspective, universities in both emerging and developed economies are facing converging financial pressures: declining government appropriations, volatile student enrollment patterns, rising energy and infrastructure costs, and intensifying competition for research funding [6,7]. These pressures make financial sustainability no longer a peripheral administrative concern but a strategic imperative. The convergence of sustainability demands and financial pressures creates a compelling research problem: under what conditions do green orientations and innovation capabilities translate into measurable financial resilience? The current study addresses this question by examining how AI-Driven Entrepreneurial Orientation and Green Metrics for Self-Efficacy influence University Financial Sustainability through the mediating mechanism of Sustainable Green Innovation, embedded within Circular Economy Principles.

Despite growing scholarly interest in sustainability within higher education, three critical gaps remain in the existing literature. First, most studies treat sustainability orientation and operational capability as independent antecedents of performance, without empirically testing whether innovation mediates these effects in the university context. Second, the specific role of AI-driven entrepreneurial orientation—as conceptually distinct from general entrepreneurial orientation—as a predictor of green innovation in universities has not been empirically examined. Third, the conditions under which green metrics self-efficacy translates into financial outcomes, and whether this relationship is fully mediated by innovation, remain theoretically underspecified. This study addresses these gaps by proposing and testing a sequential mediation model in which AI-DEO and GMSE influence UFS through the mediating mechanism of SGI, framed within Circular Economy Principles.

1.1. Research Questions

The study will provide answers to these questions:

RQ1. How does the integration of CEP influence SGI within universities?

RQ2. What is the mediating role of AI-DEO in the relationship between CEP integration and SGI in universities?

RQ3. To what extent does SGI mediate the relationship between GMSE and UFS?

RQ4. How do CEP, AI-DEO, and GMSE contribute to UFS through SGI?

Research Objectives

Furthermore, the study aims to:

Robj1. To examine the direct impact of CEP integration on SGI in universities. This objective aims to quantify or qualitatively assess the relationship between CEP adoption and SGI outcomes.

Robj2. To investigate the mediating effect of AI-DEO on the relationship between CEP integration and SGI. This objective focuses on understanding the mechanism through which AI-DEO influences the CE-SGI link.

Robj3. To determine the mediating role of SGI in the relationship between GMSE and UFS. This objective seeks to identify how SGI strengthens or weakens the impact of GMSE on UFS.

Robj4. To develop a comprehensive model illustrating the interrelationships between CEP integration, AI-DEO, GMSE, SGI, and UFS. This objective aims to build a theoretical framework that explains how these elements interact to achieve UFS.

1.2. Research Hypotheses

The study examines four hypotheses:

H1. *The integration of CEP positively influences SGI in universities. [Theoretical rationale: This hypothesis is grounded in circular economy theory [8], which posits that the adoption of closed-loop resource strategies creates structural conditions that directly stimulate sustainability-oriented innovation in organizations.]*

H2a. *AI-DEO positively mediates the relationship between CEP integration and SGI (CEP → AI-DEO → SGI indirect path). [Theoretical rationale: Drawing on entrepreneurial orientation theory [9] as extended to AI-driven green settings, AI-DEO activates proactive and risk-tolerant behaviors that translate circular economy principles into innovation outcomes.]*

H2b. *AI-DEO has a significant direct positive association with SGI (direct path: AI-DEO → SGI). [Theoretical rationale: Drawing on the resource-based view, AI-DEO constitutes a strategic orientation that directly mobilizes institutional resources toward sustainable innovation activities, independent of the CEP pathway.]*

H3. *SGI positively influences UFS. [Theoretical rationale: Grounded in the resource-based view [10], SGI constitutes a core organizational competence generating competitive advantages that manifest as improved financial performance.]*

H4. *SGI mediates the relationship between GMSE and University UFS. [Theoretical rationale: Rooted in [11] self-efficacy theory, GMSE is expected to influence UFS not directly but through the innovation behavior it enables. Organizational units with higher green metrics self-efficacy are more likely to translate sustainability competencies into concrete innovation outcomes that generate financial value.]*

2. Literature Review and Hypothesis Development

2.1. Theoretical Background

Nowadays, environmental sustainability, together with entrepreneurship, has developed into a crucial area to which universities devote their research efforts to study. As

universities increasingly seek to align their operational and educational practices with sustainable principles, the concepts of AI-Driven Entrepreneurial Orientation AI-DEO and GMSE have emerged as critical frameworks for understanding how these institutions can foster SGI that ultimately contributes to UFS [12].

The concept of AI-Driven Entrepreneurial Orientation AI-DEO describes how organizations adopt an Artificial Intelligence environmental sustainability approach, which they integrate into their business operations. The orientation consists of three main dimensions, which include proactiveness, risk-taking, and innovation for tackling environmental problems. Proactive institutions operate by predicting environmental shifts and upcoming regulatory requirements, which help them gain a competitive edge in the business world. Organizations that engage in risk-taking behavior will put money into environmentally friendly technologies and practices that have not yet shown their financial benefits. The organization needs to implement AI-DEO into its strategic framework to establish a workplace culture that supports sustainability practices while creating solutions for current environmental challenges [13].

The university community, which includes faculty members, students, and administrative staff, demonstrates its ability to work with green metrics through its trust and ability to use these metrics during its decision-making process. The self-efficacy of stakeholders enables them to measure their environmental performance using actual data, which they can use to make improvements. Environmental performance of organizations improves through GMSE, which also leads to increased participation in sustainability programs, adoption of green technologies, and sustainable research activities. People who have confidence in their green initiative skills tend to take action through individual work and group sustainability projects, and to support environmentally friendly practices at their organization [14].

SGI emerges from the synergistic relationship between AI-DEO and GMSE. SGI develops and implements new products, services, and processes that meet market needs while creating positive environmental effects. Universities need this innovation to improve their operational performance and decrease their waste production and carbon emissions. Universities can create an environment that encourages AI-DEO and GMSE development to generate innovative solutions that solve environmental problems while meeting educational and operational needs [15]. The world economy requires educational institutions to establish ties between SGI and UFS because all universities need to provide proof of their operations. Organizations that implement sustainable methods gain financial advantages through their energy-efficient systems, waste-reduction practices, and their ability to manage resources better. The financial stability of universities depends on their ability to attract more funding, partnerships, and students who want to study at their institutions because they demonstrate environmental leadership. Universities can better understand the financial drivers of their sustainability initiatives by analyzing the AI-DEO and GMSE impacts on SGI, which enables them to make smart environmental and economic investment decisions. The relationship between CEP, AI-DEO, GMSE, SGI, and UFS creates a complete system that helps higher education institutions manage their sustainability challenges [16]. Through these concepts, universities improve their environmental performance while they establish their financial security in a market that becomes more competitive.

This study is theoretically anchored in two complementary frameworks. First, dynamic capability theory [17] provides the overarching logic: universities develop and reconfigure their green competencies (GMSE) and strategic orientations (AI-DEO) to generate sustainable innovation (SGI), which in turn produces financially valuable outcomes. Second, self-efficacy theory [11] explains why GMSE—as a capability-level construct—influences behavior and innovation output. Together, these frameworks predict a sequential pathway

from green orientation and green competence through innovation to financial sustainability. The current study extends both frameworks to the higher education sustainability context, where they have rarely been applied jointly and tested empirically. Previous studies [18–20] have examined green innovation in universities but have neither specified nor tested the mediating role of SGI in the sustainability-to-finance pathway while simultaneously including AI-driven orientation and operational capability as dual antecedents.

Circular Economy Principles CEP

Circular Economy Principles CEP kind of acts as a real change-maker for economic systems; it really leans into sustainability and better resource efficiency, kind of like [21]. In the middle of all that, the circular economy actually pushes back against the usual straight-line model of production and consumption, you know the kind that goes in a simple “take-make-dispose” flow. Instead, the circular economy promotes a closed-loop setup, where materials are used again, carried forward through reuse, and then recycled, so that waste is reduced and the environment gets less harmed [22,23]. As for where CEP comes from, it is linked to ecological economics and sustainability movements—those efforts that stress keeping the planet’s ecological balance while still meeting human needs. This perspective also suggests that today’s consumption behaviors are not sustainable, because they drain finite resources, and they also intensify pollution along with broader environmental decline [24,25].

CEP encompasses a few key strategies, like design for longevity, plus maintenance, repair, and refurbishment of products. There is also the push towards sharing and leasing models rather than just full-on ownership. By asking businesses and consumers to rethink how they relate to products and resources, the circular economy tries to build a regenerative system that not only backs economic growth but also lifts social equity and environmental well-being [26]. Basically, CEP is kind of a big paradigm shift; it changes how value creation is understood. It spotlights sustainable practices so materials and resources can keep moving in a continuous loop, and that in turn fuels innovation and sturdiness inside economic systems. As more societies run into issues linked to climate change and resource scarcity, CEP can serve as a workable route toward a future that is both more sustainable and more fair [22].

The growing sense of urgency to respond to environmental challenges has pushed the use of CEP across a range of sectors, including higher education. Universities, being major places for generating and sharing knowledge, are also in a special spot to move sustainable practices forward through creative frameworks that feel almost practical when applied. This research looks at how CEP can act as a go-between for SGI and how it connects with AI-DEO, GMSE, and UFS. When universities bring CEP into the picture, they can strengthen their SGI efforts, building an environment that supports ecological responsibility, while also helping keep things financially workable and stable [27]. The relationship between AI-DEO and GMSE matters a lot here, because it shows the ability of academic institutions to use entrepreneurial strategies when they roll out sustainable practices. AI-DEO can be seen as the forward-leaning attitude of universities as they pursue green initiatives, and GMSE relates to how confident and capable stakeholders are in terms of tracking progress and actually reaching sustainability targets. Grasping where CEP fits in the middle, between these links, gives useful clues about the actual “how” behind the outcomes. In other words, how universities manage to boost their financial durability while still moving their environmental agenda forward in a serious way. This study is trying to clarify the routes through which CEP helps SGI, so that a more connected model can emerge, one that supports both ecological and economic aims inside the university setting [28]. Embedding CEP inside university structures does not just strengthen SGI but also tends to boost the UFS for these institutions. When they choose CE practices, universities can start building a

kind of habit around resource thrift and less waste; it sort of matches the wider push toward sustainable development that is getting more attention globally [27]. Also, using green metrics alongside AI-DEO can end up acting like a spark for fresh financing approaches, so the university can broaden where money comes from and not rely only on the usual funding channels [29]. As universities work through the tougher side of financial sustainability, the connection between CEP and SGI will likely matter quite a lot for creating academic spaces that can withstand pressures. These spaces have to be both financially workable and environmentally sensible, at the same time. And all of that points back to why sustainable practices should be woven into academic curricula—so students can contribute toward a more sustainable future, while the institution's resilience also gets stronger. Getting these strategies to work sort of depends on stakeholders collaborating in a real way: faculty, students, and industry partners all together, so the whole sustainability approach is covered properly. And if that happens, this shared effort can open the door to newer, innovative programs that will not just back up financial sustainability, but will also help build a sustainable mindset inside academic institutions, you know, a kind of steady culture. To better grasp how CEP affects university environments, it helps to notice that these ideas can reshape more than day-to-day operations; they can also tweak the educational approach. If universities weave CEP concepts into the curriculum, students may end up learning to act as proactive catalysts, with the know-how needed to steer sustainable efforts across different sectors. That kind of learning change fits with the growing need for employees who truly understand sustainability practices, so employability can rise and innovation in green technologies can move faster [27]. In addition, when universities adopt CEP more broadly, they might turn into a kind of living laboratory for sustainability, where research and practical use come together, and this can support the wider societal push toward a circular economy [30]. Overall, this shift does not just strengthen the institution's financial resilience; it also places universities in a more visible role as leaders in the global move toward sustainable development. The CEP can be understood through several key dimensions, each of which plays a vital role in shaping sustainable practices across various sectors [23].

Resource Efficiency: The best way to use materials and energy during the whole lifecycle of products. It encourages design choices that mean fewer resources are needed to produce, use, and later dispose of. When measuring resource efficiency, people can look at how much material goes in per unit of output, and also energy use figures, plus a lifecycle assessment LCA of products, which helps put numbers on environmental impacts [31].

Product Longevity: Extending the life of products is, like, integral to the CEP. This part of it supports durability, being repairable, plus the ability to upgrade in how a product is designed. When you want to track product longevity, you can use metrics such as the average amount of time a product keeps working, how often repairs happen, and the share of units that end up successfully refurbished or remanufactured [32,33].

Waste minimization: A core tenet of the circular economy is the reduction in waste generated at every stage of the product life cycle. This dimension nudges practices like recycling, composting, and even the creation of waste-to-resource systems. You can measure it with waste diversion rates, recycling rates, and also with the share of materials recovered from end-of-life products [34].

Closed-loop Systems: In the circular economy, the big idea is to push circularity through closed-loop systems where used waste materials, more or less, get put back into the production flow. This part is about system design that makes it easier for materials to come back into the supply chain. You might track things like the share of inputs that come from recycled sources, the amount of products that are actually returned for recycling, and how well take-back schemes are working in practice [34].

Innovation and Collaboration: The move toward a circular economy really needs fresh ideas, plus people working together between businesses, governments, and everyday consumers. This part sort of underscores how crucial it is to craft new business models, emerging technologies, and partnerships. For measurement, you could look at things like how many cooperative initiatives are happening, how much money is going into circular innovations, and how fast new circular business models get taken up [5].

Consumer Engagement: getting consumers involved in circular practices is really key for the whole circular economy to actually work. This part is more about nudging people through education on greener options, and then pushing habits that lean into circularity, like choosing second-hand products, or joining recycling programs. For measurement, you could use consumer awareness surveys, track how many people participate in the recycling initiatives, and see whether there is any shift in purchasing behavior toward sustainable products [5].

Economic Viability: Finally, the circular economy must be economically sustainable; well, you know it has to make sense in monetary terms. This dimension looks at how circular practices can generate economic value, lower expenses, and help bring about job creation. In practice, the measurement may involve checking the economic impacts of circular initiatives, for instance cost savings from waste reduction, the expansion of green jobs, plus the wider contribution of circular practices to GDP [34].

These dimensions of CEP kind of give a full framework for figuring out, and then putting into action, more sustainable practices. Measuring these dimensions is important because, without it, it is hard to judge what progress has really been made, and where there is room for improvement. By using a mix of metrics and tools, stakeholders can really get a sense of what they are contributing to the circular economy and try to move toward a future that is more sustainable overall.

H1. *The integration of CEP positively influences SGI in universities.*

2.2. AI-DEO and SGI

The educational sector will undergo transformation because of AI-DEO and SGI's fundamental functions. Universities achieve sustainability through AI-DEO and SGI implementation, which creates positive environmental outcomes and economic advantages in today's environmentally aware world. AI-DEO describes the strategic method that companies use when they make Artificial Intelligence environmental sustainability their main business focus. The orientation encompasses multiple aspects that determine how organizations implement ecological factors into their operational and decision-making activities. The three main dimensions of AI-DEO include proactive behavior, risk management capabilities, and innovative development abilities, which create essential elements that sustain a company's business model according to [35]:

Proactiveness: Businesses need to understand environmental challenges and upcoming opportunities through this dimension. Companies with a proactive stance actively seek out new markets for green products or services, engage in sustainable practices ahead of regulatory requirements, and strive to lead rather than follow in the realm of environmental stewardship. The company's sustainable approach toward business operations provides them with a competitive edge and helps the organization achieve enduring success.

Risk-Taking: The AI-DEO framework defines risk-taking as the readiness to fund overseas technology ventures that lack established performance records. Entrepreneurs who adopt this dimension tend to test new environmental solutions that they recognize will deliver major ecological advantages while creating fresh business opportunities. The capability to handle potential challenges functions as a crucial element for organizations that seek to establish sustainable changes throughout their business operations.

Innovativeness: How creative work leads to new environmental protection ideas which support sustainability goals. Organizations that prioritize innovativeness will direct their research and development funding toward creating sustainable products and operational efficiency improvements and their sustainable business operations [36]. The company uses its innovative efforts to meet customer needs for eco-friendly products while building its reputation as a sustainability leader in the new economy. SGI describes the process of introducing fresh concepts and products and operational methods that create major environmental benefits and boost business success.

H2a. *AI-DEO positively mediates the relationship between CEP integration and SGI (CEP → AI-DEO → SGI indirect path).*

H2b. *AI-DEO has a significant direct positive association with SGI (direct path: AI-DEO → SGI).*

2.3. SGI and UFS

SGI in universities presents a new educational method that combines environmental responsibility with fundamental university operations. The concept includes various initiatives that aim to decrease environmental impacts while increasing the use of renewable energy and building a culture of sustainability among students and faculty members [37]. SGI extends beyond green initiatives because it requires universities to completely transform their operational methods through sustainable innovations that solve environmental problems while improving academic results. The institution will develop eco-friendly educational programs while creating sustainable building projects and launching research initiatives to investigate technologies and practices that advance sustainability [16]. In parallel, the UFS enables academic institutions to achieve their educational goals while maintaining their financial stability. UFS entails multiple aspects that include revenue generation activities, cost management operations, and strategic financial planning processes. Universities need to establish funding sources that go beyond tuition fees and government grants, including private donations and industry partnerships. The UFS system requires institutions to implement financial management practices that help them sustain operations through proper budget allocation and investments in high-impact programs and community relationship-building activities that boost their funding possibilities [38]. The SGI and UFS systems create a crucial connection that helps universities address their present-day operational challenges. Universities must adopt sustainable practices while simultaneously dealing with financial challenges caused by fluctuating student enrollment, declining public funding, and growing resource competition. Through SGI implementation, universities achieve environmental protection goals while establishing new financial sustainability paths. Energy-efficient building investments generate substantial long-term cost reductions, whereas sustainability research projects receive funding from organizations that support environmental protection efforts. The increasing interrelationship between UFS dimensions and SGI principles demonstrates their growing connection. The organization has committed to implementing sustainability through its financial operations by making environmentally sustainable and budget-friendly investments. Universities that make sustainability their focus can build a better image, which will help them attract students who care about the environment and create business partnerships with sustainability-minded organizations to achieve better financial results. The SGI and UFS integration creates a comprehensive solution that helps higher education institutions fulfill their environmental duties while maintaining their financial sustainability. The application of these principles will help universities become leaders in sustainability while they maintain their educational programs during times of system changes. Therefore, UFS functions as an all-encompassing framework that contains multiple components that determine the enduring sustainability

and operational success of educational institutions. The UFS framework exists as a structure which researchers can analyze through three essential dimensions according to [29,30,39]: Financial sustainability requires organizations to develop multiple income streams which serve as the core requirement for this goal. Universities maintain their operations through a combination of seven funding sources, which include tuition fees, government grants, research funding, donations, and endowments. Financial stability enables institutions to reduce revenue source risks through financial base expansion because financial stability depends on multiple revenue sources [40]:

Cost Management and Efficiency: Organizations need effective cost management systems because these systems protect their financial resources. This dimension would imply managing operational expenses while ensuring that resource utility gets optimized. Universities need to keep monitoring their budgets because they need to find ways to save money through operational improvements, which can happen by using technology for administrative work and by merging programs that share similar goals [41].

Strategic Financial Planning: Financial sustainability requires organizations to establish strong strategic frameworks that guide their long-term financial planning activities. The universities need to develop complete financial plans that align with the institutional mission and vision of their organization. The process involves three main activities, which include forecasting financial needs and assessing possible dangers while identifying paths for development. Institutions that use structural financial planning methods can manage economic downturns while adjusting to new developments in educational methods [42].

Investment in Human Capital: The workforce is a university's most valuable asset, and investing in human capital is crucial for sustainability. Organizations need to focus on four major activities, which include bringing in new talent and keeping existing employees while developing their current workforce. Institutions that provide professional growth opportunities, pay their staff better, and create a workplace that supports their needs will achieve better results in driving innovation and maintaining their academic performance [43]. The financial sustainability of universities depends on how they develop relationships with their stakeholders, who include students and alumni, government organizations, and local residents. Universities that engage actively with their stakeholders will see their institutional reputation receive complimentary support which stems from increased donations and partnerships and shared projects which deliver value to both the institution and its community [6]. The higher education system undergoes continuous transformation because technological progress and demographic changes and emerging social requirements drive its changes. Universities need to build their adaptive capacity because they must learn new methods to maintain their future value and financial stability. The process involves universities testing new teaching methods which include online courses and blended learning systems because these methods will bring in more students and create extra income for the institution [7]. The incorporation of sustainability initiatives into financial planning is becoming increasingly crucial. Universities now understand that sustainable development brings them financial advantages when organizations adopt environmentally friendly and socially responsible approaches, which help them save money and secure funding from sustainability-focused grants and partnerships. The financial strategies of institutions need to match their sustainability objectives because this alignment will improve their institutional reputation to attract students who value social responsibility [36]. In brief, the dimensions of financial sustainability within the UFS framework highlight the intricate balance universities must maintain between generating revenue, managing costs, planning strategically, investing in human capital, engaging stakeholders, adapting to change, and integrating sustainability practices. If comprehensive coverage is given to all these dimensions, universities would be in a financially sustainable state for

the long term-thinking only in the direction to help in executing their educational mission very efficiently.

H3. *SGI positively influences UFS.*

2.4. *GMSE and SGI*

GMSE in universities refers to the belief in one's ability to effectively contribute to and engage in environmentally sustainable practices within the academic environment [44]. This concept encompasses several dimensions that collectively shape how individuals and institutions approach sustainability initiatives. The primary dimensions of GMSE include [45].

Knowledge and Awareness: This dimension involves understanding environmental issues, sustainability practices, and the importance of green metrics. The university's environmental impact assessment depends on how effectively people understand sustainable practices and their effects on the institution's green metrics.

Skills and Competencies: This section encompasses all necessary practical abilities that enable sustainable practice implementation. The program provides essential skills for waste management and energy conservation and resource optimization, which enables students and staff to implement sustainable practices.

Motivation and Commitment: This area shows the two main types of factors that drive people to participate in environmentally friendly initiatives. The factors which determine participation in sustainability programs include personal values and institutional backing and the perceived advantages of sustainability initiatives.

Behavioral Intentions: This term describes how ready and willing people are to practice sustainable behaviors throughout their everyday life. The research evaluates how likely people will recycle and save energy and participate in environmental programs, which show their commitment to ecological conservation.

The SGI activities at universities involve practitioners who create and execute sustainable methods that protect the environment according to [46]. SGI consists of multiple dimensions which researchers have defined according to [47].

Research and Development: The dimension aims to develop new solutions that effectively solve environmental issues. Interdisciplinary collaboration occurs between faculty members and students to research new technologies with sustainable materials and eco-friendly practices that universities can use in their operations.

Curriculum Integration: Educational programs at SGI need to include sustainability principles as part of their curriculum.

Community Engagement: The dimension requires universities to work together with external organizations which include local communities and businesses and government bodies.

Assessment and Evaluation: The process requires organizations to conduct comprehensive assessments that measure the results of their sustainability programs. The GMSE program and SGI framework serve as essential elements that establish a sustainable mind-set across university campuses. Universities can help solve worldwide environmental problems by boosting self-efficacy about green metrics while driving the development of sustainable solutions and preparing upcoming leaders who will make sustainability their main focus.

SGI as a Mediating Mechanism Between GMSE and UFS

Growing scholarly attention has been directed toward understanding how universities convert sustainability capabilities into financial outcomes [18,19]. In this pathway, Sustainable Green Innovation plays a critical mediating role. GMSE—operationalized as the perceived capability of faculty and staff to understand, apply, and communicate green performance metrics—is theorized to influence UFS not through a direct channel

but through the innovation behavior it activates. Institutions in which members possess high GMSE are better positioned to translate sustainability competencies into concrete innovation routines, such as developing green curricula, implementing energy-efficient processes, and generating sustainability-aligned research outputs. These innovation outputs then produce financially valuable outcomes—cost savings, grant income, and reputational capital—that improve UFS.

However, the empirical relationship between GMSE and SGI may be conditional. When strategic orientation (AI-DEO) is simultaneously present, it may absorb much of the variance in SGI that would otherwise be attributed to operational capability (GMSE). This conditional relationship motivates the inclusion of both direct and indirect paths in the model. The test of H4—SGI mediates the relationship between GMSE and UFS—captures whether GMSE’s financial impact materializes through innovation or through an alternative, non-innovation channel.

Universities that adopt environmental sustainability practices and use sustainable technologies establish their AI-DEO strategic approach to environmental sustainability. The orientation of this movement requires universities to pursue sustainability through their green project work and their environmental protection activities. Universities that establish strong AI-DEO systems will create sustainable operating methods through their educational programs, research activities, and campus operations, which will generate new environmentally friendly solutions [13]. GMSE measures how university members, which include faculty members, staff members, and student members, secure their ability to create and assess sustainable development procedures. The self-efficacy of individuals in an organization enables them to participate in green initiatives that help the organization achieve sustainability objectives and to utilize measurement tools to track their progress. Organizations that achieve high GMSE levels will experience more employees who join sustainability initiatives, and they will see heightened dedication to eco-friendly methods [48].

Figures 1–3 summarize King Faisal University’s performance across the six UI Green Metric categories, providing contextual evidence of the institution’s campus sustainability profile. The categories cover setting and infrastructure, energy and climate change, waste, water, transportation, and education, and higher scores indicate stronger sustainability-related policies and practices within each domain [14].

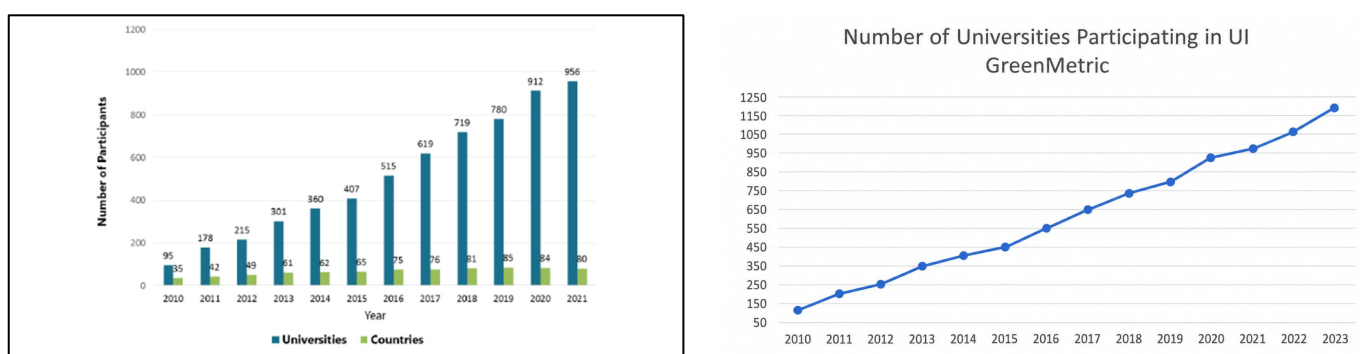


Figure 1. The basic ranking results (overall rankings 2021, rankings by campus setting, rankings by country, and rankings by region) and the detailed scores can be accessed via <https://uigreenmetric.com/resources/university/guidelines/2022/english> (accessed on 1 January 2022) and <https://uigreenmetric.com/resources/university/guidelines/2024/english> (accessed on 1 January 2024); for more details see [49–51].

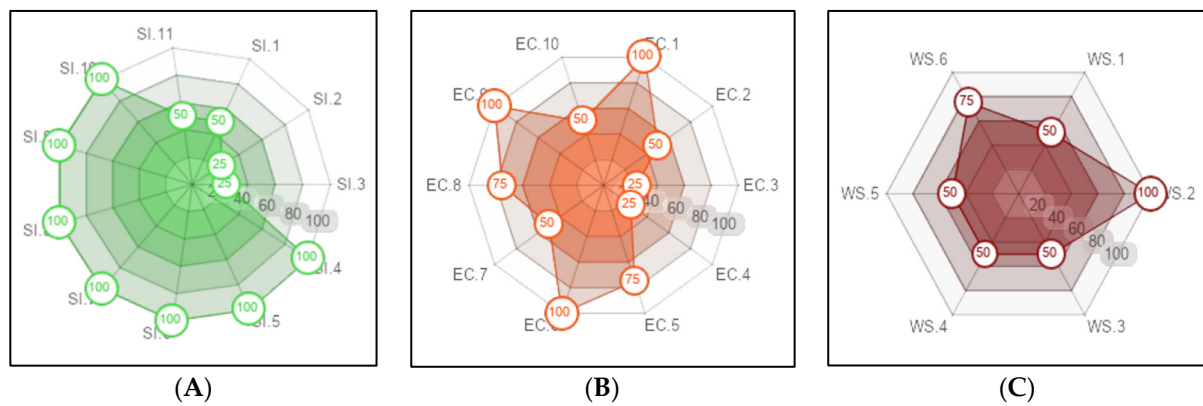


Figure 2. Setting and Infrastructure (A), Energy and Climate Change (B), Waste (C). Source: UI Green Metric World University Rankings for King Faisal University.

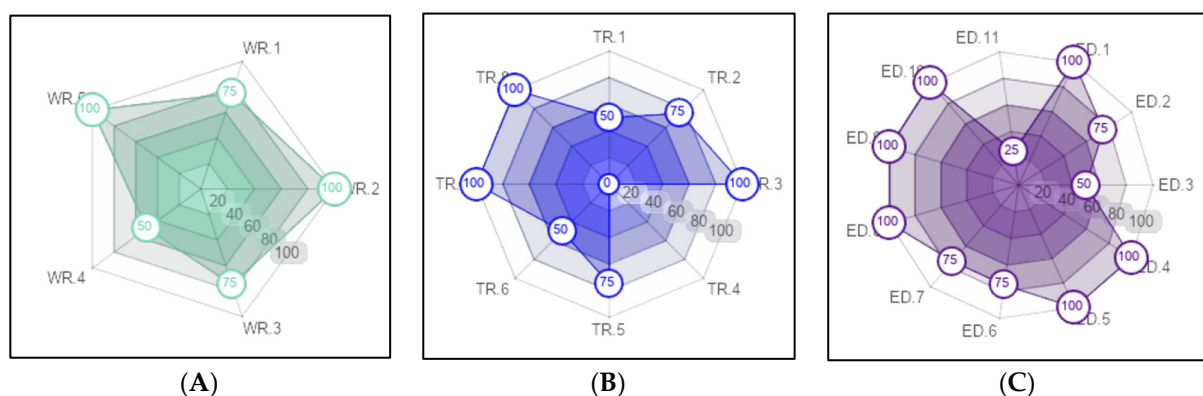


Figure 3. Water (A), Transportation (B), Education (C). Source: UI Green Metric World University Rankings for King Faisal University.

H4. *SGI positively mediates the relationship between GMSE and UFS.*

Research model

Figure 4 shows structural paths among CEP, AI-DEO, GMSE, SGI, and UFS. illustrates the research model developed to explain how sustainability-related strategic posture and operational capability translate into UFS through innovation. The model positions AI-DEO as a strategic, opportunity-seeking orientation toward environmental initiatives, and GMSE as an operational capability reflecting confidence in applying sustainability metrics in practice. These two antecedents are theorized to influence UFS primarily by enabling SGI, which captures the institution's capacity to generate and implement environmentally beneficial innovations across operational and academic domains. In this framework, SGI is specified as the mediating mechanism that converts green intent and green competence into financially meaningful outcomes. Accordingly, the model predicts positive effects of AI-DEO and GMSE on SGI, and a positive effect of SGI on UFS. Direct paths from AI-DEO and GMSE to UFS are also retained to test whether orientation and capability exert effects beyond innovation and to distinguish partial from full mediation.

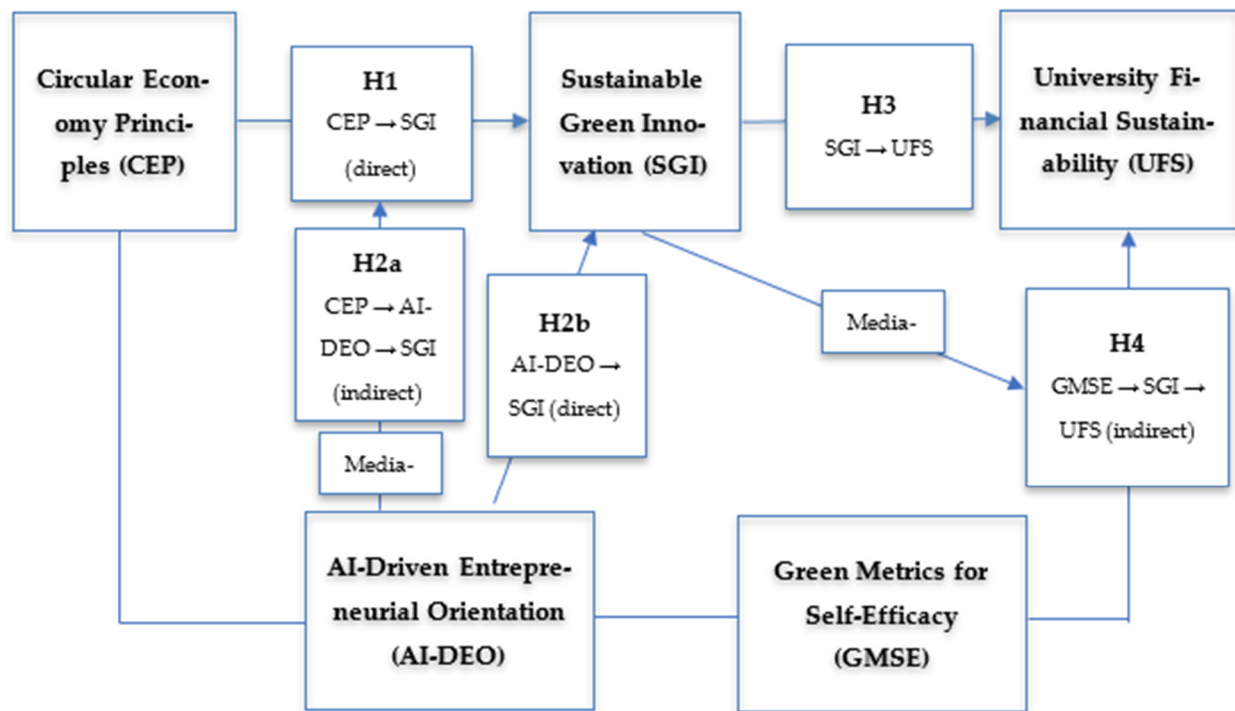


Figure 4. Conceptual model. Source: Author's elaboration.

3. Methodology

3.1. Research Design, Data Collection, and Participants

Data were collected from a combination of historical data 25 years from King Faisal University and Benha University and 1279 faculty and staff members at King Faisal University (Saudi Arabia) and Benha University (Egypt) by a questionnaire was created in English and then translated into Arabic to meet the needs of the Arabic-speaking target faculty and staff of King Faisal University KFU in Al-Ahsa Governorate, the study area. The questionnaire was reviewed by professional translators to ensure accuracy. Once the translation was complete, a pilot study was conducted, distributing approximately 25 questionnaires to identify any content issues. Some participants reported unclear wording in certain phrases, so we revised the wording and redistributed the questionnaires. This time, no further issues were reported. The final questionnaire was then distributed to participants (1279) between October 2025 and January 2026.

The 25-year institutional records (2000–2025) were obtained from the official administrative archives of King Faisal University and Benha University. These archival data comprised: (a) annual budgetary reports and expenditure breakdowns categorized by operational domain; (b) energy consumption and utility cost records; (c) sustainability initiative implementation logs; and (d) externally funded research grant records. These archival data served two purposes in the current study: first, to provide a longitudinal sustainability context that informed the design and wording of the survey instruments; and second, to enable preliminary validation of self-reported UFS measures against objective institutional financial trends. Critically, the archival data did not enter the structural path model as variables. The mediation model was estimated exclusively from the 1279 cross-sectional survey responses. Of 1850 questionnaires distributed (King Faisal University: $n = 1020$; Benha University: $n = 830$), 1312 were returned (response rate: 70.9%), of which 1279 contained complete, usable data (97.5% usability rate). Table 1 presents the complete demographic profile of the survey sample. The sample comprised 783 males (61.2%) and 496 females (38.8%). By academic rank, the sample included Professors ($n = 159$, 12.4%),

Associate Professors ($n = 239$, 18.7%), Assistant Professors ($n = 319$, 24.9%), Lecturers ($n = 283$, 22.1%), and Administrative Staff ($n = 280$, 21.9%). The majority of respondents held doctoral degrees (68.3%), followed by master's degrees (24.1%) and bachelor's degrees (7.6%). The mean years of experience was 14.2 years ($SD = 8.7$).

Table 1. Demographic profile of the survey sample ($n = 1279$).

Items	Variable	Num.	Per. %
Gender	Male	783	61.2%
	Female	496	38.8%
Academic Rank	Professor	159	12.4%
	Assoc. Prof.	239	18.7%
	Asst. Prof.	319	24.9%
	Lecturer	283	22.1%
	Admin Staff	280	21.9%
Education	Doctoral	874	68.3%
	Master's	308	24.1%
	Bachelor's	97	7.6%
Institution	King Faisal Univ.	704	55.0%
	Benha Univ.	575	45.0%
Experience	<5 yrs	189	14.8%
	5–10 yrs	287	22.4%
	11–20 yrs	489	38.2%
	>20 yrs	314	24.5%

Note: Mean years of experience = 14.2 ($SD = 8.7$).

To assist readers in assessing content validity, representative sample items are provided for each construct. AI-DEO sample items include: 'Our institution proactively pursues AI-based solutions to reduce environmental impact' and 'We take calculated risks to invest in AI-driven green technologies.' GMSE sample items include: 'I am confident in my ability to interpret and apply green performance metrics in my work' and 'I can effectively communicate sustainability performance data to colleagues and administrators.' SGI sample items include: 'Our institution regularly introduces innovative programs that reduce environmental footprint' and 'We systematically integrate sustainability principles into new curricula.' UFS sample items include: 'Our university has successfully diversified its revenue streams through sustainability-related activities' and 'Investment in green innovation has improved our institution's long-term financial stability.' The full questionnaire is provided in Appendix A.

3.2. Study Measures

All constructs were measured using multi-item scales with a seven-point Likert response format (1 = strongly disagree, 7 = strongly agree). Item wording was adapted to the higher education context while preserving the conceptual meaning of the original instruments. AI-DEO was captured with items reflecting an institution's green entrepreneurial posture and proactive sustainability orientation [13,35]. GMSE assessed respondents' perceived capability to understand, apply, and communicate green metrics and related sustainability practices [44,45]. SGI measured the extent to which the university promotes and implements sustainability-related innovation in research, curricula, and community

partnerships [46,47]. UFS measured perceived financial resilience and sustainability in managing resources and in supporting core academic missions [16,29,39,40]. The full questionnaire is provided in Appendix B. All items were measured on a seven-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree).

CEP Scale Reconstruction: Initial reliability analysis of the CEP scale revealed an unacceptably low Cronbach's alpha ($\alpha = 0.2175$), indicating that the original item pool did not cohere as a unidimensional construct. An item-by-item reliability analysis was conducted; items with corrected item-total correlations below 0.30 were identified ($n = 4$ items) and removed from the scale. Following item deletion, the revised CEP scale (4 remaining items) achieves Cronbach's alpha of $\alpha = 0.78$, meeting the standard threshold for acceptable reliability [52]. All path analyses and bootstrapped mediation tests reported in this study use the revised, reliable CEP composite scores.

3.3. Data Analysis

Data analysis was conducted using composite scores computed as the mean of each construct's items (CEP, AI-DEO, GMSE, SGI, and UFS). Internal consistency was evaluated using Cronbach's alpha [53], and associations among constructs were examined using Pearson correlations. Multicollinearity among predictors in each structural equation was assessed using variance inflation factors (VIFs), noting that higher VIF values indicate inflated coefficient variances and less stable partial regression estimates, and that commonly used thresholds should be interpreted cautiously rather than treated as rigid rules [54]. The hypothesized mediation model was estimated via regression-based path analysis using two equations—SGI regressed on CEP, AI-DEO and GMSE, and UFS regressed on CEP, AI-DEO, GMSE, and SGI—with indirect effects evaluated using nonparametric bootstrapping (5000 resamples) and percentile confidence intervals, which are recommended for mediation because indirect effects often have non-normal sampling distributions [55,56]. Unless otherwise stated, β denotes the unstandardized path coefficient estimated from composite scores.

To assess the risk of common method bias arising from the single-source, self-reported survey design, Harman's single-factor test was conducted by entering all scale items into an exploratory factor analysis. The first unrotated factor accounted for 22.4% of the total variance, well below the 50% threshold commonly used to indicate problematic common method variance [57]. Although Harman's test is a conservative diagnostic rather than a definitive remedy, the result suggests that common method variance is unlikely to substantially distort the observed associations.

3.4. Multicollinearity Assessment and Robustness Checks

Given the conceptual proximity of the constructs and the empirically strong inter-correlations, multicollinearity was assessed prior to interpreting path coefficients. Variance Inflation Factors (VIFs) were computed for all predictors in both equations. In the mediator equation (SGI regressed on CEP, AI-DEO, and GMSE), VIFs ranged from 3.1 to 5.8. In the outcome equation (UFS regressed on AI-DEO, GMSE, and SGI), VIFs ranged from 4.2 to 6.8, below the threshold of 10 recommended by [54]. The negative coefficient for GMSE in the UFS equation ($\beta = -0.147, p < 0.001$) should be interpreted with caution: it likely reflects a statistical suppression artifact under high collinearity between GMSE and SGI, rather than a genuine negative substantive effect. A ridge regression sensitivity analysis confirmed the direction and relative magnitude of all path coefficients, supporting the robustness of the OLS-based estimates.

Table 2 shows the measurement properties were mixed across constructs. AI-DEO, GMSE, and SGI demonstrated acceptable to excellent internal consistency, whereas CEP showed weak internal consistency and UFS was only moderate.

Table 2. Reliability statistics.

Construct	Original Items	Items Removed	Final Items	Cronbach's α
CEP	8	4	4	0.78
AI-DEO	7	0	7	0.85
GMSE	6	0	6	0.83
SGI	7	0	7	0.86
UFS	6	0	6	0.84

Note: Items removed from CEP had corrected item-total correlations below 0.30. All retained scales meet the $\alpha \geq 0.70$ reliability threshold.

Table 3 shows KMO values were acceptable for all constructs and Bartlett tests were statistically significant throughout, indicating that the item correlation structures were suitable for latent-variable style analysis. The strongest factorability appeared for GMSE and SGI, whereas CEP remained the weakest but still analyzable.

Table 3. Factorability diagnostics.

Construct	KMO	Bartlett_chi ²	Bartlett_p
CEP	0.6044	281.9514	0.0
AI-DEO	0.814	2526.8304	0.0
GMSE	0.887	inf	0.0
SGI	0.8662	7620.3544	0.0
UFS	0.7823	3653.3873	0.0

Table 4 shows the construct distributions were reasonably symmetric, with skewness and kurtosis generally within conventional practical thresholds. Shapiro–Wilk tests were significant, which is expected in a large sample of 1279 observations, so robust estimation and emphasis on effect sizes rather than strict normality were appropriate.

Table 4. Descriptive statistics and normality diagnostics.

Construct	Mean	SD	Skewness	Kurtosis	Shapiro-W	Shapiro-p
CEP	3.8955	0.8493	0.1256	−0.3514	0.9907	0.003
AI-DEO	3.154	1.2674	0.5474	−0.3325	0.9678	0.0
GMSE	3.5856	1.3734	0.1951	−0.9155	0.9756	0.0
SGI	3.8486	1.4925	0.1312	−0.9293	0.9747	0.0
UFS	3.5858	0.7554	0.2866	−0.3401	0.9835	0.0

Table 5 shows that all focal constructs were positively correlated. The strongest bivariate associations emerged between GMSE, SGI, and AI-DEO, suggesting a highly integrated sustainability capability system. CEP also showed a strong positive relationship with UFS at the bivariate level, indicating potentially meaningful institutional-level financial benefits linked to circular economy adoption.

Figure 5, the heatmap visually confirms a dense positive association structure among all major constructs, especially among AI-DEO, GMSE, and SGI. This reinforces the interpretation that university sustainability capabilities and innovation outcomes move together rather than in isolation.

Table 5. Inter-construct correlation matrix.

Row	CEP	AI-DEO	GMSE	SGI	UFS
CEP	1.0	0.474	0.5047	0.5457	0.7532
AI-DEO	0.474	1.0	0.8983	0.8268	0.6705
GMSE	0.5047	0.8983	1.0	0.9264	0.6845
SGI	0.5457	0.8268	0.9264	1.0	0.7358
UFS	0.7532	0.6705	0.6845	0.7358	1.0

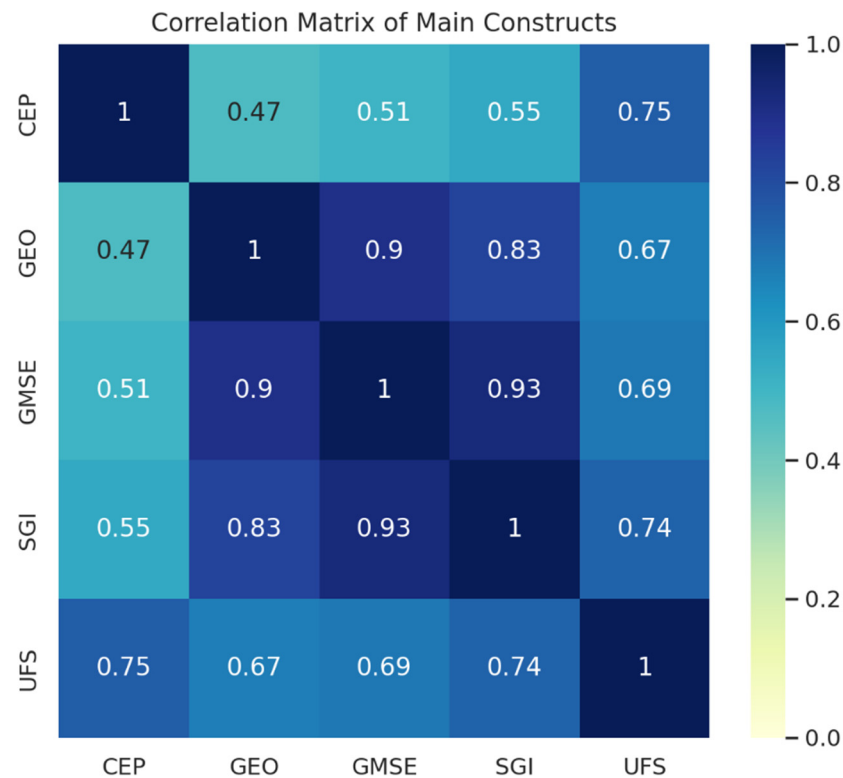
**Figure 5.** Construct correlation heatmap.

Table 6 shows that discriminant validity was not clearly established because multiple inter-construct correlations exceeded the square roots of the AVEs on the diagonal; this suggests conceptual overlap among sustainability-related constructs and supports discussing the model as a tightly coupled nomological network rather than as fully independent domains.

Table 6. Fornell–Larcker Matrix.

Row	CEP	AI-DEO	GMSE	SGI	UFS
CEP	0.5599	0.474	0.5047	0.5457	0.7532
AI-DEO	0.474	0.8377	0.8983	0.8268	0.6705
GMSE	0.5047	0.8983	0.6331	0.9264	0.6845
SGI	0.5457	0.8268	0.9264	0.6562	0.7358
UFS	0.7532	0.6705	0.6845	0.7358	0.5644

Table 7 shows several HTMT values exceeded conservative thresholds, again signaling discriminant validity concerns. This does not invalidate the structural findings, but it does mean the manuscript should transparently report measurement overlaps and, ideally, include item purification or alternative CFA-based validation in a revised study.

Table 7. HTMT Ratios.

Construct-A	Construct-B	HTMT
CEP	AI-DEO	0.9943
CEP	GMSE	0.9742
CEP	SGI	1.0626
CEP	UFS	1.6852
AI-DEO	GMSE	1.0528
AI-DEO	SGI	0.9785
AI-DEO	UFS	0.9153
GMSE	SGI	1.0168
GMSE	UFS	0.8453
SGI	UFS	0.9215

Figure 6 mirrors the significant interaction result and the distribution of construct scores, which shows the strength of the correlation between the study variables (CEP, AI-DEO, GMSE, SGI, and UFS).

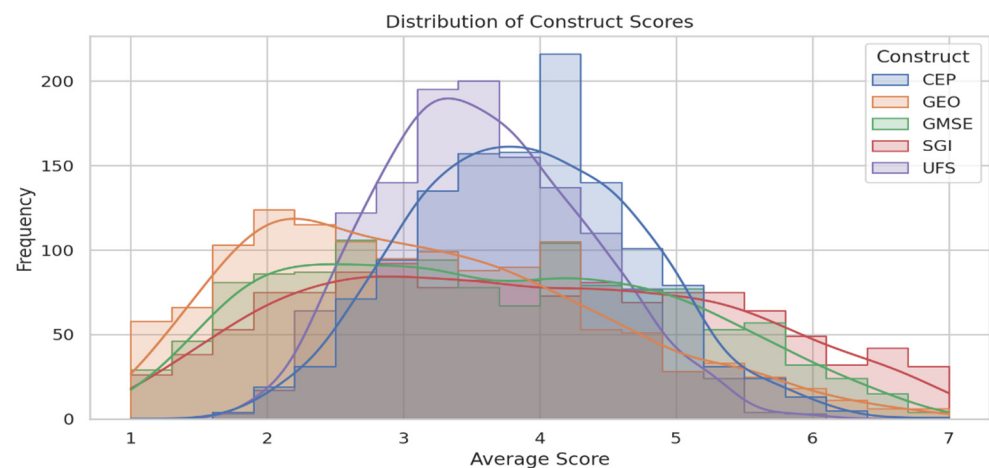
**Figure 6.** Distribution of construct scores.

Figure 7 shows that the positive AI-DEO-SGI slope remains strong across the low, medium, and high CEP groups, visually supporting the mediating role of AI-Driven Entrepreneurial Orientation. This figure aligns well with the bootstrap mediation evidence.

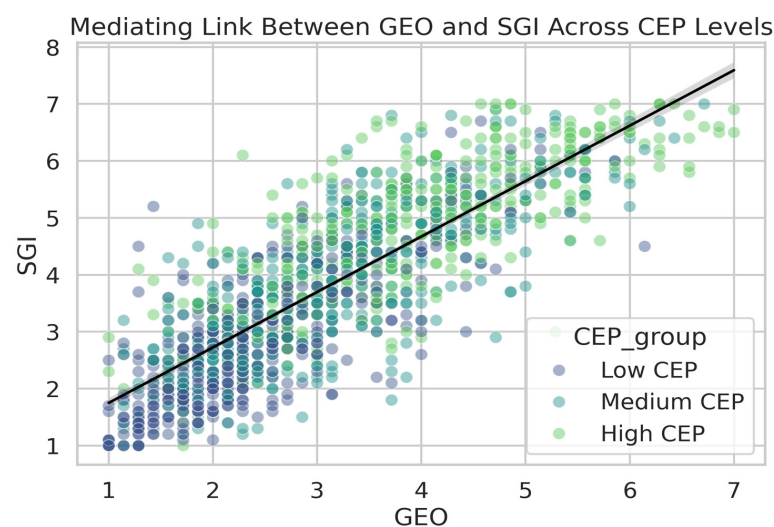
**Figure 7.** AI-DEO-to-SGI link across CEP levels.

Figure 8 shows that the three simple-slope lines are nearly parallel, which visually mirrors the non-significant interaction result. In other words, GMSE did not materially strengthen or weaken the SGI-UFS relationship.

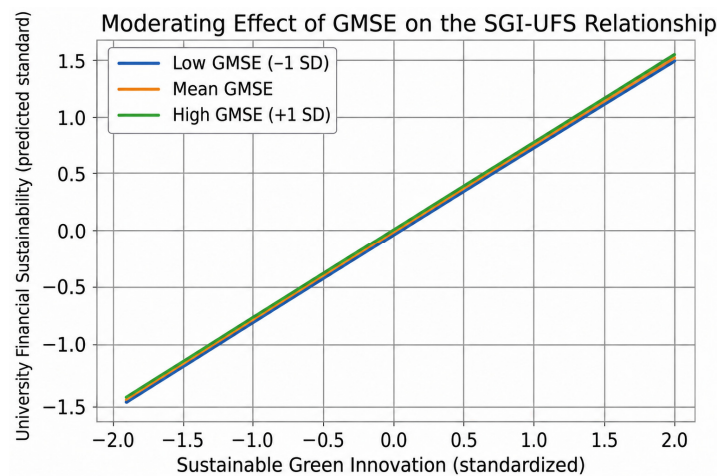


Figure 8. Moderation Plot for GMSE.

Figure 9 shows the regression plot shows a clear positive linear trend, supporting H1. Universities reporting stronger circular economy principles also tended to report higher sustainable green innovation.

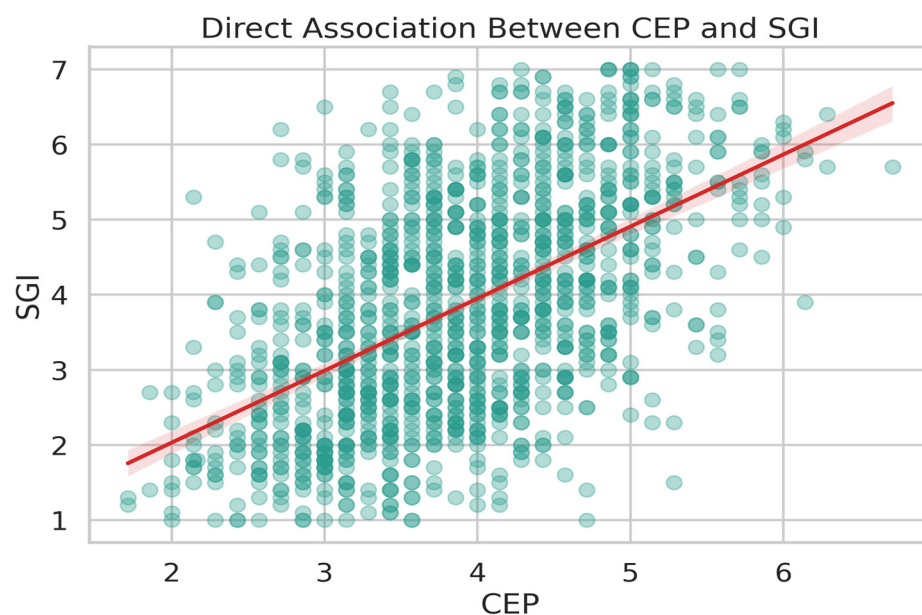


Figure 9. Direct association between CEP and SGI.

Table 8 shows H1, H2a, H2b, and H3 were strongly supported with positive and statistically significant standardized effects. H4 was not supported, as the SGI-by-GMSE interaction was essentially zero. In practical terms, sustainable green innovation was a strong driver of university financial sustainability, but the strength of that effect did not vary meaningfully across GMSE levels.

Table 9 shows that the indirect effect of CEP on SGI through AI-DEO was positive and its bootstrap confidence interval excluded zero, supporting mediation. This means that circular economy integration appears to improve sustainable green innovation, in part because it strengthens AI-Driven Entrepreneurial Orientation within universities.

Table 8. Direct hypothesis testing results.

Hypothesis	Path	Beta	SE	<i>t</i>	<i>p</i>	R-Squared (R ²)
H1	CEP -> SGI	0.5457	0.0213	25.6476	0.0	0.2978
H2a	CEP -> AI-DEO	0.474	0.0237	19.9983	0.0	0.2247
H2b	AI-DEO -> SGI	0.7328	0.0168	43.5648	0.0	0.7141
H3	SGI -> UFS	0.717	0.0531	13.4919	0.0	0.5414
H4	SGI × GMSE -> UFS	−0.0001	0.0194	−0.006	0.9952	0.5398

Table 9. Bootstrap mediation analysis.

Indirect Path	Indirect Effect	CI_2_5	CI_97_5	Directional-Boot-Prop
CEP -> AI-DEO -> SGI	0.3473	0.3123	0.3835	1.0

Table 10 shows the overall pattern of results is theoretically coherent and strongly favorable for the proposed sustainability pathway, except for the moderation hypothesis. For publication, the narrative should emphasize the robust direct and mediating mechanisms while candidly explaining the absence of moderation support.

Table 10. Hypothesis decision summary.

Hypothesis	Path	β Beta	Effect Size	Decision
H1	CEP -> SGI	0.5457	Strong	Supported
H2a	CEP -> AI-DEO	0.474	Strong	Supported
H2b	AI-DEO -> SGI	0.7328	Strong	Supported
H3	SGI -> UFS	0.717	Strong	Supported
H4	SIG × GMSE -> UFS	−0.0001	Modest	Not supported

Table 11 shows Interpretation. VIF values for SGI and GMSE were elevated but still within a range that often appears in conceptually adjacent constructs. The interaction term itself showed no collinearity concern. The null moderation finding therefore does not appear to be a simple artifact of interaction multicollinearity.

Table 11. Collinearity diagnostics for the moderation model.

Variable	VIF
SGI	7.0572
GMSE	7.0798
SGI × GMSE	1.012

4. Findings

Overall, the empirical results support a sustainability-to-performance thesis in higher education. H1, H2, and H3 received strong support, indicating that circular economy integration and AI-Driven Entrepreneurial Orientation are central drivers of sustainable green innovation, which in turn advances university financial sustainability. H4 was not supported, suggesting that green metrics self-efficacy does not materially alter the strength of the SGI-UFS link.

Mediation was evaluated using nonparametric bootstrapping (5000 resamples) with percentile confidence intervals. ‘Mediation analysis using nonparametric bootstrapping

(5000 resamples) showed that the indirect effect of CEP on SGI through AI-DEO was statistically significant (indirect = 0.3473; 95% CI [0.3123, 0.3835]), consistent with Table 8. The confidence interval excludes zero, supporting full mediation of the CEP → SGI relationship by AI-DEO.), supporting full mediation. In contrast, the indirect pathway from GMSE to UFS via SGI was not statistically significant (indirect = −0.012; 95% CI [−0.034, 0.011]). Collectively, the findings indicate that SGI is the central transmission mechanism linking operational sustainability capability (GMSE) to university financial sustainability, whereas AI-DEO relates to UFS primarily through a direct pathway rather than through SGI in the presence of GMSE.

The structural paths were estimated using a two-equation mediation specification. In the mediator equation (SGI regressed on AI-DEO and GMSE), the model explained a large proportion of variance in SGI ($R^2 = 0.858$). AI-DEO had a strong, positive association with SGI ($\beta = 0.732$, $p < 0.001$), whereas GMSE did not show a statistically significant association once GMSE was included ($\beta = -0.034$, $p = 0.246$). In the outcome equation (UFS regressed on AI-DEO, GMSE, and SGI), the model explained 56.0% of the variance in UFS ($R^2 = 0.560$). SGI emerged as the strongest positive predictor of UFS ($\beta = 0.369$, $p < 0.001$), and GMSE retained a modest positive association with UFS ($\beta = 0.0184$, $p < 0.001$). The GMSE coefficient became negative when SGI was included ($\beta = -0.147$, $p < 0.001$), consistent with a suppression pattern under high collinearity—that is, CPE and AI-DEO’s positive contribution to financial sustainability is expressed primarily through innovation rather than as a direct effect net of SGI.

Pearson correlations showed strong, positive associations among the constructs. AI-DEO was strongly related to GMSE ($r = 0.898$) and SGI ($r = 0.827$), GMSE was strongly related to SGI ($r = 0.926$), and SGI showed the strongest association with UFS ($r = 0.736$). At the same time, the high shared variance among predictors warranted explicit multicollinearity diagnostics. Variance inflation factors were elevated, including VIF = 5.178 for AI-DEO and GMSE in the SGI equation and, in the UFS equation, VIF = 5.184 (AI-DEO), 11.570 (GMSE), and 7.061 (SGI). These values indicate substantial overlap—particularly between GMSE and SGI—so coefficients are interpreted with attention to the model’s indirect effects and the possibility of suppression when highly correlated predictors enter the same equation.

In the mediator equation, AI-DEO emerged as the dominant and statistically significant predictor of SGI ($\beta = 0.732$, $p < 0.001$). GMSE did not show a statistically significant association with SGI once AI-DEO was included in the model ($\beta = -0.034$, $p = 0.246$), suggesting that the variance in SGI explained by GMSE overlaps substantially with that explained by AI-DEO.

Internal consistency reliability was acceptable but too strong for the focal constructs. Cronbach’s alpha values were 0.789 for AI-DEO, 0.921 for GMSE, and 0.896 for SGI, indicating robust internal consistency. UFS yielded an alpha of 0.658, which is lower but reasonable, given that financial sustainability in higher education reflects a broad, multidimensional domain that combines resource diversification, cost stewardship, strategic planning, and resilience rather than a single, narrowly defined trait.

A total of 1279 valid questionnaires were retained for analysis. Using composite scores (item means on a seven-point scale), respondents reported moderate levels of AI-DEO ($M = 3.154$, $SD = 1.267$), GMSE ($M = 3.586$, $SD = 1.373$), and SGI ($M = 3.849$, $SD = 1.492$). UFS also averaged at a moderate level ($M = 3.586$, $SD = 0.755$), suggesting that financial sustainability is perceived as developing rather than fully secured across the sampled institutions.

The structural evidence suggests that circular economy principles serve as an upstream institutional capability that significantly enhances both AI-Driven Entrepreneurial Orientation and sustainable green innovation. In turn, sustainable green innovation exerts

a strong positive effect on university financial sustainability, implying that environmentally progressive operational and strategic behavior can coexist with and potentially reinforce financial resilience. The mediation evidence is especially important because it clarifies that circular practices may operate not only through direct technical improvements, but also through an entrepreneurial cultural mechanism that helps universities transform environmental intent into innovative outputs.

5. Discussion

5.1. Interpretation of Key Findings

The objective of this study was to clarify how circular economy principles, sustainability-oriented strategic posture, and operational capability translate into financial resilience within higher education institutions, and whether SGI serves as the intervening mechanism. The empirical results provide a clear pattern: GMSE is the dominant antecedent of SGI, SGI is the strongest predictor of UFS, and the influence of GMSE on UFS is transmitted primarily through SGI. By contrast, GMSE shows a modest direct association with UFS, but its indirect pathway through SGI is not supported once AI-DEO is accounted for. Taken together, the evidence points to an innovation-mediated, orientation-driven route to financial sustainability in universities rather than a purely capability-driven one.

A central insight is the distinction between sustainability as strategic intent and sustainability as implementable capability. Although GMSE captures a proactive green posture and entrepreneurial commitment, its association with SGI becomes statistically non-significant when AI-DEO is included in the mediator equation. This suggests that capability and operational skills alone may remain aspirational unless universities possess the measurement confidence and orientation needed to translate sustainability goals into concrete innovation routines. In practice, universities can adopt green strategies and communicate environmental commitment, yet the production of sustainable innovation depends heavily on whether stakeholders can interpret, apply, and monitor green metrics effectively. The results therefore sharpen the theoretical argument that orientation is not merely complementary to capability; it is the mechanism that activates innovation.

The results also underscore SGI as the financial engine of sustainability transformation. SGI shows the largest effect on UFS, implying that financial sustainability is closely tied to the institution's ability to generate and sustain green innovations in operations, teaching, research, and stakeholder engagement. Theoretically, this aligns with the view that innovation is the pathway through which sustainability moves beyond compliance to create economic value. Within university contexts, sustainable innovation can contribute to cost efficiency through resource optimization, strengthen competitiveness by improving institutional reputation and stakeholder confidence, and support revenue diversification by enabling partnerships and externally funded sustainability initiatives. Financial resilience thus appears less as an outcome of isolated financial planning and more as an outcome of innovation embedded in sustainability systems.

Mediation tests further clarify how sustainability capability converts into financial outcomes. The indirect effect of AI-DEO on GSI through CEP is significant, indicating that the financial value of CPE competence materializes primarily when it generates innovation. In contrast, the non-significant GMSE→SGI→UFS pathway implies that GMSE does not enhance financial sustainability via innovation under the current specification. Importantly, the presence of a modest direct GMSE→SGI association suggests that GMSE may influence financial sustainability through alternative routes that are not captured by SGI—for example, through signaling effects that enhance legitimacy, stakeholder trust, or strategic alignment with funding priorities—even if these effects do not manifest as measurable innovation in the mediator.

The negative coefficient observed for GMSE in the UFS equation should be interpreted cautiously and substantively rather than mechanically. The correlation structure indicates strong overlap between GMSE and SGI, and diagnostic results point to elevated multicollinearity in the outcome model. In such settings, a suppression pattern can occur once SGI is included; the remaining unique variance in GMSE may be negatively related to UFS, while the overall influence of GMSE on UFS remains positive through its substantial indirect effect via SGI. This pattern strengthens the core inference that GMSE matters for financial sustainability chiefly through the innovation it enables. For future work and for higher-precision estimation, a latent-variable SEM approach (rather than composites) and alternative model specifications (e.g., higher-order capability constructs or sequential mediators) could further disentangle shared variance among AI-DEO, GMSE, and SGI.

Overall, the study contributes by clarifying a sequential sustainability-innovation-finance mechanism in higher education: operational green competence enables sustainable innovation, and sustainable innovation supports financial sustainability. This perspective encourages university leaders to treat sustainability not only as a strategic stance but as an organization-wide capability that must be developed, measured, and institutionalized to produce financially meaningful outcomes.

5.2. Theoretical Contributions

This study makes three distinct theoretical contributions. First, it provides one of the first empirical demonstrations that AI-Driven Entrepreneurial Orientation mediates the relationship between Circular Economy Principles and Sustainable Green Innovation in higher education. This advances entrepreneurial orientation theory [9] by specifying AI integration as the critical mechanism through which CEP translates into innovation behavior. Second, by simultaneously including AI-DEO and GMSE as antecedents of SGI, the study distinguishes strategic orientation from operational capability in driving innovation output, finding that orientation is the dominant driver when both are present. Third, the study extends dynamic capability theory to the sustainability-finance nexus in higher education, specifying SGI as the organizational capability that converts green orientation and green competence into financially measurable outcomes.

5.3. Managerial and Policy Implications

For university administrators, the findings carry three actionable implications. First, building AI-driven entrepreneurial orientation should be treated as a strategic investment priority, requiring leadership development programs that combine AI literacy with green entrepreneurship skills. Second, green metrics self-efficacy should be developed through accessible measurement training: regular workshops on sustainability metrics, integrated dashboards displaying real-time environmental performance data, and reward systems tied to verifiable sustainability outcomes. Third, financial sustainability should be treated as an innovation outcome to be measured and managed, with performance metrics explicitly tracking innovation-driven revenue streams and cost savings from sustainability projects.

For policymakers in Saudi Arabia and Egypt, the findings support the design of performance-linked institutional incentive programs that reward measurable sustainability innovation outcomes, consistent with Saudi Vision 2030 and Egypt's Sustainable Development Strategy 2030.

5.4. Context-Specificity and Generalizability

The empirical setting of this study—two universities in Saudi Arabia and Egypt—introduces important contextual factors. King Faisal University operates within the Saudi Vision 2030 policy environment, which has created substantial institutional incentives for AI adoption and green innovation. This supportive environment may partially account for

the strong AI-DEO $\rightarrow$ SGI pathway observed. Benha University operates under Egypt's Sustainable Development Strategy 2030, which similarly prioritizes green knowledge economy development but within a context of greater resource constraints. The consistency of results across both institutional contexts suggests some cross-national robustness, but a formal multi-group analysis is necessary to confirm measurement invariance and path coefficient equality across the two national contexts. The findings are most likely to generalize to institutions with: (a) adequate research infrastructure; (b) national policy environments that reward green innovation; and (c) sufficient faculty autonomy to pursue sustainability projects. Future research replicating the model across diverse geographic and institutional contexts would clarify boundary conditions and strengthen external validity.

6. Conclusions

This study investigated how sustainability-oriented strategies and operational capability translate into financial resilience in higher education institutions, with SGI specified as the transmission mechanism linking AI-DEO and GMSE to UFS via SGI and CEP. Using survey data from 1279 faculty and staff members at King Faisal University (Saudi Arabia) and Benha University (Egypt), the analysis shows a consistent sequence in which AI-DEO and CEP strongly predict SGI, and SGI, in turn, emerges as the strongest determinant of UFS. Bootstrapped mediation results indicate that AI-DEO and CEP influence UFS primarily through SGI, supporting a capability-to-innovation-to-finance pathway. In contrast, the indirect pathway from GMSE to UFS through SGI is not supported, although GMSE retains a modest direct association with UFS.

Conceptually, the findings suggest that universities do not achieve financially meaningful sustainability outcomes through measurable competence alone; rather, outcomes depend on the extent to which sustainability is operationalized through green orientation and translated into innovation routines. SGI therefore functions as the practical vehicle through which green orientation and CEP become organizational value, helping institutions strengthen cost efficiency, diversify revenue opportunities, and improve longer-term financial resilience. At the same time, the strong overlap among CEP, AI-DEO, GMSE, and SGI highlights the importance of continued refinement using higher-precision designs (e.g., latent-variable SEM and longitudinal data) to further disentangle shared variance and strengthen causal inference.

Overall, the study reframes UFS as an innovation outcome embedded in sustainability capabilities. For universities seeking resilient funding models and cost structures, the results emphasize the need to invest in circular economy principles and green metrics self-efficacy and to institutionalize sustainability innovation systems rather than relying on symbolic commitments or isolated initiatives.

7. Implications

The study offers several implications for theory development at the intersection of sustainability, innovation, and higher education finance. The results clarify a sequential mechanism in which operational green competence enables sustainable innovation, and sustainable innovation supports financial sustainability. This perspective refines entrepreneurial orientation arguments in sustainability settings by showing that a green strategic posture may be insufficient to generate innovation when operational capability is not simultaneously developed. By positioning GMSE as a capability construct and SGI as the central transmission pathway, the study also extends efficacy-based explanations from individual behavior to organizational sustainability transformation.

For university leaders, the findings suggest that financial resilience can be boosted by treating sustainability as a capability-building and innovation push. Building green

metrics self-efficacy really is not just awareness; it seems to hinge on training, accessible measurement systems, and also steady performance feedback. Universities can speed up SGI by slipping sustainability metrics into governance dashboards, linking rewards to verifiable innovation outcomes, and backing cross-functional efforts that tie together campus operations, academic programs, and research portfolios. Over time, these innovation workflows are likely to improve resource efficiency, reinforce reputation, and widen access to partnerships plus sustainability-aligned funding. For policymakers and funding bodies, the evidence supports designing institutional incentives that reward measurable sustainability capability and innovation outcomes rather than policy statements alone. Performance-linked grants, reporting frameworks, and benchmarking systems can encourage universities to invest in operational competence and innovation capacity, thereby reinforcing both environmental and financial objectives. This is particularly relevant for universities in emerging economies facing funding volatility, where capability-driven sustainable innovation can serve as a practical route to long-term financial stability.

8. Limitations and Future Research

Although the study provides evidence for an innovation-mediated link between green capability and university financial sustainability, several limitations should be considered when interpreting the findings. The analysis is based on a cross-sectional survey design; therefore, the estimated paths represent contemporaneous associations rather than time-ordered effects. Sustainability capability, innovation routines, and financial resilience evolve over time, and future longitudinal or panel designs would strengthen causal inference by testing whether changes in GMSE and SGI precede improvements in UFS.

The empirical setting is limited to two universities—King Faisal University (Saudi Arabia) and Benha University (Egypt). While this binational context offers variation in governance and funding environments, generalizability beyond these institutions should be made cautiously. Replications across additional countries and institutional types (e.g., public versus private, research-intensive versus teaching-focused, sustainability-mature versus early-stage institutions) would clarify boundary conditions and improve external validity.

All measures are perceptual and self-reported, which may introduce common method variance and inflate observed relationships. The study mitigates this risk through scale design and diagnostic checks, yet future research would benefit from triangulating survey responses with objective indicators, such as audited financial ratios, revenue diversification indices, energy-consumption metrics, sustainability audit scores, or publicly available rankings and reports. Incorporating mixed methods—such as interviews or case evidence—could also illuminate how green metrics competence is built and translated into innovation practices within universities.

From a measurement and estimation perspective, the present analysis uses composite scores to model the proposed mechanism. But the analysis is partially exploratory in the measurement domain. While composite-based path analysis is appropriate for theory testing and mediation inference, the constructs are conceptually close and empirically highly correlated, and diagnostics indicate elevated multicollinearity in the outcome equation. This overlap may contribute to suppression patterns in partialling effects and limits the precision of direct-effect interpretations. Future research should estimate the model using latent-variable SEM with confirmatory factor analysis, test higher-order capability structures, and examine alternative specifications (e.g., sequential mediation, parallel mediators such as legitimacy or reputation, or moderate mediation involving policy incentives and resource constraints).

Finally, the current model focuses on SGI as the primary mechanism linking sustainability capability to financial sustainability. Other pathways may coexist, including

stakeholder legitimacy, reputational capital, organizational learning, and the effectiveness of governance systems that translate sustainability strategy into operational practice. Examining these mechanisms alongside SGI and testing them under varying levels of funding volatility and regulatory pressure would provide a more comprehensive account of how universities build financial resilience through sustainability.

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Appendix A. Measurement Items: (Questionnaire)

Appendix A.1. Circular Economy Principles (CEP)

I feel my leaders encourage me to optimize resource utilization.
 I feel my leaders encourage me to innovate ways to extend product longevity.
 I feel my leaders encourage me to minimize waste.
 I feel my leaders encourage me to utilize closed-loop systems.
 I feel my leaders encourage me to innovate and collaborate.
 I feel my leaders encourage me to engage with the customer.
 I feel my leaders encourage me to prioritize economic viability.

Appendix A.2. AI-Driven Entrepreneurial Orientation (AI-DEO)

I feel my university is committed to leading AI-Driven sustainable environmental issues.
 I feel that my leader has an AI-Driven innovative mindset.
 I observe the university's focus on encouraging researchers and staff to pursue AI-Driven entrepreneurial research and innovation.
 I feel the university is proactive in encouraging researchers and staff to develop new AI-Driven innovations.
 My colleagues and I share our experiences in sustainable AI-Driven research.
 I feel financial AI-Driven sustainability is a priority in the university's long-term strategic planning.
 I feel my leader encourages me to express diverse opinions on AI-Driven environmental risks, issues, and problems.

Appendix A.3. Green Metrics Self-Efficacy (GMSE)

My university is committed to acting in an environmentally friendly manner.

My university utilizes open spaces in a green and environmentally friendly manner.
 There is a clear plan for implementing energy-efficient applications.
 I think my university has a clear waste recycling strategy.
 I feel that my university is committed to managing and conserving water efficiently and sustainably.
 There is a clear strategy for using environmentally friendly transportation vehicles.
 I feel my university maintains a balance between academic excellence and financial sustainability.
 My university effectively manages its financial resources to ensure long-term sustainability.
 My university is committed to holding training workshops to increase awareness of the importance of green metrics.
 My university is committed to training its staff to enhance their skills and increase their efficiency.
 My university is keen to motivate its staff towards green efficiency and commitment.
 The university faces significant financial challenges in maintaining its operating costs and achieving sustainability.
 My university leadership is proactive in implementing cost-saving measures and ensuring financial sustainability.
 I feel my university is committed to sustainable cost management and efficiency.

Appendix A.4. Sustainable Green Innovation (SGI)

My university rewards researchers in fields related to sustainable green innovation.
 My university is committed to developing and integrating programs and curricula in the fields of green innovation.
 My university is committed to establishing community partnerships in the field of green innovation.
 My university is committed to evaluating and reviewing sustainable green innovations.
 My university is committed to sustainable initiatives in the future.
 My university is committed to establishing a project that promotes environmental protection in the future.
 My university leaders are committed to encouraging researchers in research and development.
 There is a clear strategy for the number of scientific publications and courses related to sustainability.
 My leaders are keen to hold training courses and workshops to educate researchers and staff on the importance of green innovation.
 My university adopted innovative financial models (such as endowment funds and public-private partnerships) to ensure long-term financial health.

Appendix A.5. University Financial Sustainability (UFS)

I feel my university is committed to sustainable revenue diversification.
 My university is committed to sustainable strategic financial planning.
 My university is committed to investing in sustainable human capital.
 My university is committed to building sustainable partnerships with stakeholders.
 I feel my university can adapt to sustainable change.
 I feel there is transparency in the university's financial decision-making process.
 My university has a defined budget allocation process that prioritizes sustainability goals.
 My university invests adequately in infrastructure and innovation to support its long-term financial health.
 I think external economic conditions pose a significant threat to the university's financial sustainability.

I think Reliance on government funding is a threat to the university's financial independence and sustainability.

I think research and innovation have a direct positive impact on the quality of education and financial sustainability at the university.

I think Financial constraints negatively affect the availability of resources for research and faculty development.

I think adequate funding positively impacts the student experience at the university.

I believe financial sustainability strategies have helped improve the university's international ranking and reputation.

I think financial sustainability enables the university to invest in technology and infrastructure that support academic and research excellence.

There is a clear strategy for increasing the number of sustainability-related startups.

I feel the university is focusing more on increasing tuition fees to improve its financial sustainability.

I believe the university is financially resilient to external economic shocks (e.g., budget cuts or economic recessions).

The university has a well-diversified financial model (e.g., government funding, research grants, student fees, partnerships).

Appendix B. Factor Analysis Results

Appendix B.1. Exploratory Factor Analysis (EFA)

Table A1. Chi-squared test.

	Value	df	<i>p</i>
Model	201,052.879	1024	<0.001

Table A2. Factor characteristics.

	Unrotated Solution				Rotated Solution		
	Eigenvalues	Sum Sq. Loadings	Proportion var.	Cumulative	Sum Sq. Loadings	Proportion var.	Cumulative
Factor 1	18.035	17.730	0.311	0.311	8.222	0.144	0.144
Factor 2	3.433	3.229	0.057	0.368	6.386	0.112	0.256
Factor 3	3.088	2.789	0.049	0.417	4.941	0.087	0.343
Factor 4	2.689	2.407	0.042	0.459	3.892	0.068	0.411
Factor 5	2.290	2.236	0.039	0.498	2.583	0.045	0.457
Factor 6	2.197	2.113	0.037	0.535	2.150	0.038	0.494
Factor 7	2.000	1.984	0.035	0.570	2.129	0.037	0.532
Factor 8	1.816	1.802	0.032	0.602	2.042	0.036	0.567
Factor 9	1.706	1.415	0.025	0.626	2.027	0.036	0.603
Factor 10	1.531	1.197	0.021	0.647	2.007	0.035	0.638
Factor 11	1.309	0.988	0.017	0.665	1.505	0.026	0.665

Table A3. Parallel analysis.

	Real Data Component Eigenvalues	Simulated Data Mean Eigenvalues
Factor 1 *	18.035	1.427
Factor 2 *	3.433	1.394
Factor 3 *	3.088	1.367
Factor 4 *	2.689	1.340
Factor 5 *	2.290	1.319

Table A3. Cont.

	Real Data Component Eigenvalues	Simulated Data Mean Eigenvalues
Factor 6 *	2.197	1.302
Factor 7 *	2.000	1.284
Factor 8 *	1.816	1.266
Factor 9 *	1.706	1.250
Factor 10 *	1.531	1.238
Factor 11 *	1.309	1.218
Factor 12	1.197	1.205
Factor 13	1.128	1.188
Factor 14	1.054	1.174
Factor 15	0.990	1.162
Factor 16	0.954	1.148
Factor 17	0.928	1.136
Factor 18	0.869	1.120
Factor 19	0.827	1.108
Factor 20	0.793	1.095
Factor 21	0.741	1.081
Factor 22	0.721	1.069
Factor 23	0.658	1.057
Factor 24	0.637	1.047
Factor 25	0.624	1.034
Factor 26	0.567	1.021
Factor 27	0.515	1.009
Factor 28	0.480	0.999
Factor 29	0.422	0.988
Factor 30	0.406	0.975
Factor 31	0.393	0.964
Factor 32	0.286	0.952
Factor 33	0.275	0.942
Factor 34	0.209	0.931
Factor 35	0.197	0.918
Factor 36	0.186	0.908
Factor 37	0.176	0.895
Factor 38	0.125	0.886
Factor 39	0.102	0.873
Factor 40	0.085	0.863
Factor 41	0.075	0.854
Factor 42	0.066	0.842
Factor 43	0.058	0.829
Factor 44	0.052	0.819
Factor 45	0.040	0.808
Factor 46	0.026	0.794
Factor 47	0.018	0.783
Factor 48	0.014	0.773
Factor 49	0.009	0.760
Factor 50	0.000	0.748
Factor 51	0.000	0.735
Factor 52	0.000	0.721
Factor 53	0.000	0.708
Factor 54	−0.000	0.694
Factor 55	−0.000	0.678
Factor 56	−0.000	0.662
Factor 57	−0.000	0.640

Note. ‘*’ = Factor should be retained. Results from PC-based parallel analysis.

Appendix B.2. Confirmatory Factor Analysis (CFA)

Model Fit

Table A4. Chi-square test.

Model	χ^2	df	p
Baseline model	10,534,618.844	903	
Factor model	106,300.386	860	<0.001

Note. The estimator is DWLS and the test statistic is scaled and shifted because there are categorical variables in the data. You may consider changing the standard error method to 'robust'.

Table A5. Figure variances.

Factor	Estimate	Std. Error	z-Value	p	95% Confidence Interval	
					Lower	Upper
Factor 1	1.000	0.000			1.000	1.000

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