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Transformative Approaches to Sustainable Education: Technology, Leadership and SDGs in Higher Education Institutions

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Abstract. The present study examines the relationship between the adoption of technology, the implementation of sustainable leadership practices, guided by Transformational Leadership Theory, and the attainment and the attainment of Sustainable Development Goals (SDGs) at academic institutions in Saudi Arabia. The study used a questionnaire-based technique from students, alumni and professors. The population consists of students, alumni and professors from these institutions, with a sample size of 383 participants. The research approach employed in this study is Partial Least Squares Structural Equation Modeling (PLS-SEM), a robust statistical technique. PLS-SEM enables simultaneous analysis of multiple variables, making it ideal for exploring complex relationships in the data. The results highlight the favorable influence of incorporating technology and implementing sustainable leadership practices on achieving SDGs. The study emphasizes its significant contributions to objectives, including clean energy, responsible consumption and reduced inequalities. The research also highlights the importance of involving stakeholders and implementing strategies that promote environmental sustainability practices in higher academic institutions. The study indicates that educational institutions, policymakers and stakeholders should take note of the practical consequences. It emphasizes the significance of making strategic technological investments, fostering sustainable leadership and spreading awareness to advance sustainability activities. The findings enhance our comprehension of the intricate relationships associated with attaining SDGs, underscoring the necessity of adopting a comprehensive strategy that encompasses leadership, technology, culture and stakeholder involvement.

Keywords: Technology Adoption; Sustainable Leadership; Sustainable Development Goals; Sustainability Awareness; Academic Institutions

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1. Background of the study

In an era of rapid technological advancements and growing global awareness of sustainability concerns, integrating technology adoption (TA) and sustainable leadership practices (SLP) has become a critical priority (Najjar et al., 2023; Suhluli & Ali Khan, 2022). Academic institutions and communities throughout the globe are facing a growing need to effectively navigate this ever-changing environment, not only to maintain their competitiveness but also to make significant contributions toward achieving the SDGs (Chaiyasit et al., 2023; Hajikhani & Suominen, 2022) set forth by the United Nations (UN) (González-Campo et al., 2022; SDG-2, 2022). Saudi Arabia, under the influence of its transformative initiative known as "Saudi Vision 2030" (Alharthi et al., 2019; Islam & Faisal Ali Khan, 2023), serves as an intriguing subject for analysis within this particular framework. The nation strives to expand its intellectual horizons, promote sustainability and align its endeavors with global development goals. Notwithstanding the ambitious objectives outlined in Saudi Vision 2030, there is a notable deficiency in scholarly study about comprehending the complex interconnections among TA (Chumnumporn et al., 2022), SLPs and the advancement and consequences of SDGs within the academic institutions of Saudi Arabia.

The integration of TA and SLP into universities is anticipated to have a substantial influence on the progress and impact of SDG PI. TA, SLP, and SDGs in academic institutions are a multifaceted area of study with rich literature. Extensive research has been conducted to explore how the integration of technology and SLPs can contribute to the achievement of SDGs in educational settings (Islam & Ali Khan, 2024b). Regarding TA, scholars have examined the role of various technologies, including information and communication technology (ICT), renewable energy technologies and digital platforms, in promoting sustainability initiatives within academic institutions. Studies have highlighted the potential of technology to enhance energy efficiency, facilitate resource management, and foster collaboration among stakeholders in support of SDGs related to clean energy (SDG 7) and climate action (SDG 13) (Hakami et al., 2023; Islam & Faisal Ali Khan, 2023). Sustainable leadership theory, particularly Transformational Leadership Theory (Tang et al., 2022), has garnered attention for its emphasis on ethical, visionary and socially responsible leadership practices. Research in this area has explored how leaders within academic institutions can inspire and empower stakeholders to embrace sustainability principles, align organizational strategies with SDGs, and cultivate a culture of environmental stewardship. Sustainable leadership has been linked to advancements in responsible consumption (SDG 12) and partnerships for sustainable development (UN, 2015).

Furthermore, the literature underscores the interconnected nature of TA, SLP and SDGs, highlighting the need for a holistic approach to sustainability in higher education. Studies have emphasized the importance of stakeholder engagement, interdisciplinary collaboration and the integration of sustainability principles into academic curricula and institutional policies. By fostering awareness, innovation and collective action, educational institutions can contribute significantly to SDGs related to quality education (SDG 4), decent

work and economic growth (SDG 8), reduced inequalities (SDG 10), and industry, innovation and infrastructure (SDG 9).

Environmental sustainability practices within institutions (SSP) are hypothesized to work as a mediating mechanism, enabling the conversion of technology uptake and leadership commitment into concrete sustainability results. Furthermore, stakeholder engagement (SE) for SLP is anticipated to provide a comparable intermediary function, hence establishing a more vital link between the implementation of sustainable technology and leadership practices and its influence on the SDGs. The moderating variable, AWS, is suggested to have an impact on and determine the connections among these variables, emphasizing the significance of an institutional culture that prioritizes sustainability in achieving SDGs. This conceptual framework serves as the foundation for investigating the intricate relationships among TA, SLP, SSP (Stakeholder Sustainability Practice within Academic Institutions), SE (Stakeholder Engagement for Sustainable Leadership Practice), AWS and SDG PI within the research landscape.

The primary objective of this study is to address the existing disparity by examining the diverse aspects of TA and SLPs among universities in Saudi Arabia. The study examines the incorporation of sustainable leadership concepts, the dedication of leaders to sustainability objectives, and the use of sustainability frameworks. Furthermore, the present study investigates the significance of mediating factors, such as implementing environmental sustainability measures and SE, in influencing sustainable results by examining sustainability awareness as a moderating factor. The analysis seeks to contribute to the ongoing discussion on global sustainability and fill the existing research void about Saudi Vision 2030.

The research aims to comprehensively understand the intricate dynamics among these crucial factors in Saudi Arabia. By doing so, it seeks to offer valuable insights that can be utilized by policymakers and stakeholders who are dedicated to promoting sustainable development in academia. Moreover, the results of this research can make a valuable contribution to the broader international comprehension of how technology, leadership and sustainability converge to influence the trajectory of societies.

The significance of our research lies in its potential to advance sustainability practices within academic institutions, thereby contributing to broader global sustainability objectives. By elucidating the positive impact of TA and SLPs on SDGs, our study underscores the pivotal role that universities can play in fostering environmental stewardship and social responsibility. This insight not only informs current practices but also serves as a blueprint for future initiatives aimed at promoting sustainability within academic settings.

There is little research on how universities actively contribute to the SDGs in terms of quality education. Several have focused on how organizations have achieved sustainability goals but less on how academic institutions connect their operations with the SDGs in the context of Saudi Arabian universities. Since academic institutions make up a significant part of the global landscape and

contribute to sustainable development, understanding their context and dynamics in connection with sustainability and the SDGs is vital.

2. Literature Review

The SDGs signify a worldwide commitment to tackle urgent environmental, social, and economic issues (Bennich et al., 2020; Erin et al., 2022). The attainment of these objectives necessitates the utilization of inventive methodologies, and the convergence of technology and sustainable leadership has emerged as a propitious pathway (Gerard et al., 2017; Piwowar-Sulej & Iqbal, 2023; Shehawy & Ali Khan, 2024). The present literature analysis offers valuable insights into technology's significant role in promoting and enhancing SLPs to address the SDGs among academic institutions in Saudi Arabia effectively.

The study adopted the Transformational Leadership Theory (Siangchokyoo et al., 2020) for the current research of its exceptional relevance and efficacy in promoting sustainable practice and quality education. The theory proposed by Bass (1985) offers a comprehensive framework for comprehending leadership that surpasses conventional management methods. It highlights how leaders inspire, motivate and reshape their teams by presenting a compelling vision and fostering an innovative culture. Transformational leadership in sustainable institutions (Liu et al., 2020) directly focuses on the crucial connections between leadership and the adoption of technology (Purbiyantari et al., 2023; Shuib et al., 2019), the implementation of environmental sustainability practices within academic institutions (Muralidharan & Pathak, 2018), the engagement and support of stakeholders (Balwant et al., 2020) for SLPs, the awareness of sustainability and the SDG PI and quality education. The literature has widely recognized its effect on the adoption of technology, incorporation of sustainable practices, involvement of stakeholders in sustainability efforts, understanding of sustainability concerns and alignment with global sustainability objectives toward quality education. The study selects this extensive and proven theory to serve as a solid theoretical basis for examining sustainable leadership and its contribution to promoting environmental sustainability and achieving SDG effect in academic institutions emphasizing universities. Hence, based on the previous reviews, the following framework for the study has been developed, as illustrated in Figure 1.

SDG PI pertains to the quantification and assessment of the forward movement and consequences of endeavors undertaken to attain the SDGs (Erin et al., 2022). The SDGs encompass a comprehensive collection of 17 worldwide objectives formulated by the UN. These goals aim to tackle urgent global issues about poverty, inequality, climate change, environmental sustainability, peace and various other areas of concern. The process of monitoring the development of SDGs and evaluating their impact entails the systematic observation and measurement of designated indicators and outcomes linked to each target. This enables the assessment of the extent to which advancements have been achieved in attaining these goals, as well as the examination of the consequences of these endeavors on different dimensions of society, the economy and the environment. In essence, this entails assessing the efficacy of initiatives and

policies targeted at achieving the SDGs and comprehending their impact on worldwide progress and welfare (UN, 2015).

2.1 Conceptual Framework of the Study

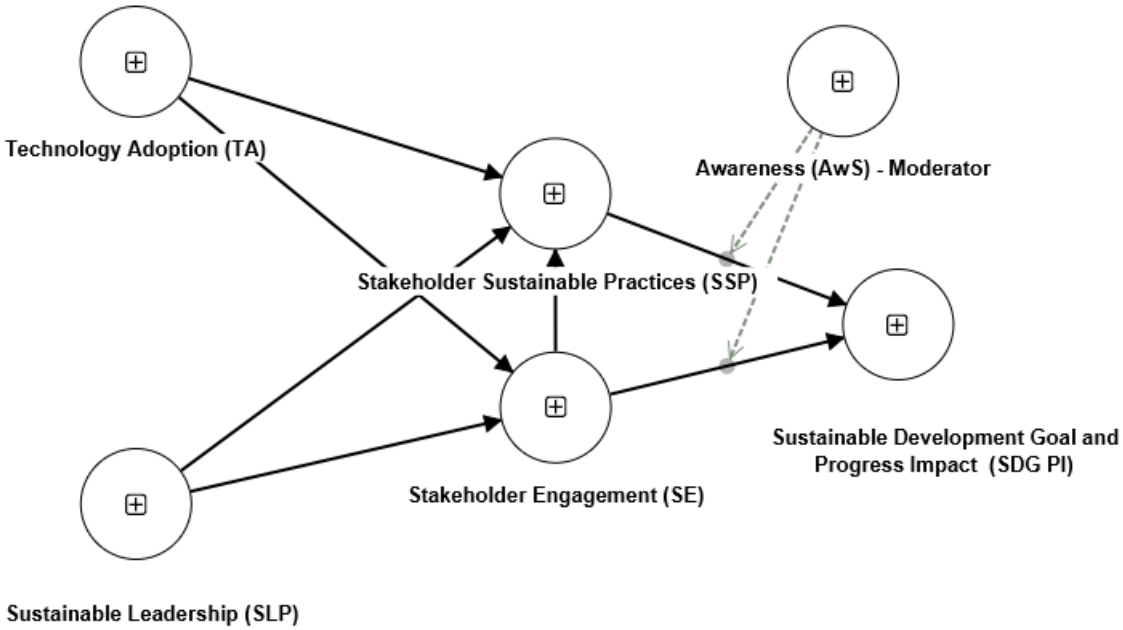

Figure 1: Framework of Study (Source: Author)

2.2 Technology Adoption and SDG Progress and Impact

Like other nations worldwide, Saudi universities are confronted with the significant task of attaining the SDGs established by the UN. The implementation of technology and the adoption of environmentally sustainable practices are essential to effectively tackle climate change by addressing SDG 13 (Department of Economic and Social Affairs, n.d.). Within this particular context, there is an increasing acknowledgment of the crucial significance that the adoption of technology, the specific sorts of technologies employed, and the extent of investment in technical infrastructure have in promoting the achievement of these SDGs (Alharthi et al., 2019; Ashraf Alwy Balabel & Hamad Raja Almujibah, 2022; Berawi, 2016). The purpose of this literature study is to examine the correlation between the level of TA, the types of technologies utilized, infrastructure investment and their collective influence on the advancement of SDGs in Saudi Arabian Universities. Studies have mentioned that the adoption of innovative technologies, such as big data analytics, is seen as a critical enabler for addressing societal challenges, including those targeting the SDGs. However, there needs to be more appreciation for the organizational issues associated with societal challenges, specifically those targeting the SDGs (El-Haddadeh et al., 2021). Challenges related to the SDG indicator framework include overburdening of national statistical systems, coordination failures and lack of funding for statistical modernization. Solutions proposed include aligning global requirements with national priorities and establishing a global financing facility for development data (Avendano et al., 2020). Barriers to TA in the public sector include a need for top management support, resources, user

involvement, awareness, training, change resistance and cultural and structural changes. Proposed change management strategies include top management support, more resources, and user involvement in project development (Abdelhakim et al., 2022).

2.3 Digital Transformation Initiatives

Saudi Arabia has undertaken ambitious digital transformation programs, exemplified by Vision 2030, that prioritize the use of technology across multiple institutions (Alshuaibi, 2017). The significant incorporation of technology is positioned to have a crucial impact on expediting advancements toward the achievement of SDGs and quality education within the nation (Schwindenhammer & Gonglach, 2021).

2.4 E-University Services

E-University Services offer many services that improve education quality and accessibility (Zekaj, 2023). Virtual classrooms allow students to hear lectures and engage in discussions remotely. Interactive modules, e-books and multimedia tools enrich educational content. E-University Services also offer digital tests and comments to evaluate student achievement quickly (Quinonez-Beltran et al., 2023). Online enrollment systems, digital grading platforms, and communication technologies streamline student, instructor and administrative staff interactions. E-University Services use AI and data analytics to personalize learning and track student success. Collaborative technologies and platforms encourage student-faculty interaction, building community and improving learning (Bamaga et al., 2024). These services make education more flexible and accessible and advance SDG 4 by meeting the worldwide need for quality education.

2.5 Sustainable Leadership and SDG Progress and Impact

University leadership practices are crucial to achieving the SDGs. As educational and research institutions, universities need to promote sustainable development. Sustainable leadership includes environmental protection, social responsibility, and ethical decision-making (Sathorar et al., 2023). Sustainability in universities' core activities can boost SDG progress. This includes green campus activities, energy-efficient technologies and responsible consumption and production. Sustainable leadership goes beyond infrastructure and operations to include academic programs in sustainable development. SDG-related content in university courses promotes student knowledge and accountability (Islam & Ali Khan, 2024a; Shishakly et al., 2024). Sustainable leadership also encourages research that addresses SDG-related global issues. Innovative solutions to poverty, climate change and inequality may require interdisciplinary collaborations. Universities empower students and staff to improve their communities by promoting sustainability. Sustainable university leadership practices affect campus operations, academic courses and research, which impacts SDG progress. Universities contribute to the global SDGs effort through various projects, improving the world's sustainable development trajectory.

2.6 Stakeholder Engagement

In higher education, stakeholder participation is crucial for promoting sustainability practices and quality education. Students, instructors, staff, communities, industry partners and governments are stakeholders. Effective SE

promotes teamwork, decision-making and sustainability activities, according to research. University stakeholders have varied interests and viewpoints, making engagement strategies essential for meaningful and inclusive sustainability outcomes (AlShamsi & Quirke, 2023; Ibrahim et al., 2024). Universities influence sustainable practices through teaching, research and operations. Higher education sustainability includes environmental, social and economic factors. University sustainability literature covers green campus efforts, curriculum integration and responsible resource management. Leadership commitment, institutional regulations and sustainability principles in institutional culture are crucial to sustainable practice implementation, according to research (Vargas-Merino et al., 2024). Research on the relationship between stakeholder participation and sustainability in universities is ongoing. Effective SE helps achieve sustainability goals. Studies emphasize open communication, collaboration and different voices in decision-making. Engagement of stakeholders can provide insights, resources and support for more comprehensive and practical university sustainability projects (Solano-Olivares et al., 2024). Literature acknowledges difficulties in balancing multiple stakeholder interests, ensuring meaningful engagement and overcoming change opposition. It also shows how universities may innovate and lead in sustainability by utilizing stakeholder expertise, developing collaborations and aligning sustainability goals with education and societal well-being. Hence, university SE and sustainability practices literature emphasize their interconnectedness and the need for collaborative, inclusive and strategic approaches to achieve the SDGs.

Research highlights challenges in SE, such as fragmented understanding of SDGs, lack of leadership from government, and overemphasis on goal-based focus (Banerjee et al., 2020). Additionally, constraints on projects to meet deadlines and concerns about overburdening stakeholders can reduce SE (O'Shea et al., 2021). Despite challenges, SE is crucial for SDG progress. It is emphasized that meaningful engagement of business, in partnership with a broader circle of stakeholders, is essential for positive transformation and SDG realization (Amato, 2021).

2.7 Stakeholder Sustainability Practice

University sustainability and stakeholder strategies are essential to ethical and impactful higher education. Effective SE is critical to university sustainability, according to the research. Students, instructors, staff, local communities, industry partners and policymakers are stakeholders. Research repeatedly shows that strong stakeholder practices identify key stakeholders, understand their perspectives, and incorporate their input into decision-making (Cayabas et al., 2023; Gonzalez-Torres et al., 2023). Building a university sustainability vision requires effective communication and engagement with these varied groups (Krishnamurthy & Sahay, 2023). University sustainability practices integrate environmental, social and economic factors. Campus operations, academic programmers and institutional policies should incorporate sustainability concepts, according to the literature. Discussions include green campus efforts, responsible resource management and curriculum design for sustainability. Leadership commitment and a sustainable institutional culture are typically

cited as critical factors in these strategies' success (Akudugu & Ogwu, 2024). Stakeholder practices and sustainability at universities are crucial for lasting influence. Engaged stakeholders provide insights and resources and keep institutions accountable for sustainability. The literature regularly shows that stakeholder participation boosts sustainability programmers' legitimacy and credibility, resulting in better environmental and social success (Abidi & Faisal AU Khan, 2018; Mulyani, 2024). Stakeholder practices and university sustainability are also linked to the global sustainability agenda, particularly the UN SDGs. University practices must connect with SDGs, and literature typically examines how SE can affect SDGs. SDGs in university sustainability activities help address global issues and ensure that local efforts contribute to global goals. Finally, university stakeholder practices and sustainability programmers are interdependent, as shown by the literature. Effective SE enhances university sustainability practices and positions higher education institutions as critical contributors to the global sustainability agenda, notably through SDG alignment.

2.8 Sustainability Awareness

The influence of sustainability awareness (Medabesh & Khan, 2020) on academic institutions and individuals (Alsaati et al., 2020; M. Khan & Chawla, 2015) plays a crucial role in the impact of technological advancements on SDG PI (Zhou et al., 2022), as it affects the level of commitment toward sustainable practices. Previous studies have demonstrated that fostering AWS can significantly help the advancement of SDGs (Leiva-Brondo et al., 2022) in institutions.

Hence, from the above literature review following hypothesis could be postulated:

H1: Technology Adoption has a significant impact on SDG Progress and Impact.

H2: Sustainable Leadership has a significant impact on SDG Progress and Impact.

H3: Sustainability Awareness moderates the relationship between Technology Adoption and SDG Progress and Impact.

H4: Sustainability Awareness moderates the relationship between Sustainable Leadership and SDG Progress and Impact

3. Research Methodology

For this investigation, a cross-sectional survey design was chosen as the research methodology (Zangirolami-Raimundo et al., 2018). This design allows the researcher to collect data from a large number of participants efficiently. With this survey design, quantitative data collection is also possible (Allwood, 2012). Quantitative research uses positive (concrete) data as numbers to be measured and statistics to derive conclusions about the topic. The quantitative analysis validates theories by generating new hypotheses to address problems and by validating prior research. Explanatory research uses hypothesis testing to explain the correlations between variables.

3.1 Data Collection

The study's primary data collection instrument was a questionnaire devised with the investigation's objectives in mind and drawing on prior research. The questionnaire was meticulously crafted to elicit information pertinent to the study objectives, focusing on variables such as TA, SLPs and SDGs attainment. The design of the questionnaire encompassed a mix of closed-ended and Likert-scale questions, allowing for both quantitative analysis and qualitative insights. Questions were formulated to gauge participants' perceptions, attitudes and behaviors related to TA, SLP and SDG PI. The sample included students, alumni and faculty (teaching and non-teaching) from selected Saudi universities. The sampling process in this study comprised two technique. A purposive sampling method was used to choose five public and private universities located in various geographic locations of Saudi Arabia. In addition, snowball sampling was used to acquire information from the faculties of these institutions. Sampling encompassed both public and private institutions to ensure comprehensive representation. The deliberate inclusion of universities from diverse sectors aimed to capture a broad spectrum of perspectives and practices within the academic landscape. This strategic approach to sampling at the initial level facilitated a more nuanced understanding of the relationship between TA, SLP and SDG PI across different institutional settings and contexts. Sampling was conducted using a stratified random sampling approach to ensure representation across different academic departments and levels within the institutions. The population targeted comprised students, alumni and professors actively engaged in educational activities. Response rates were monitored throughout the data collection process to assess the level of participant engagement. Efforts were made to maximize response rates through personalized communication, reminders and incentives where appropriate.

The response rate was calculated as the percentage of completed questionnaires returned relative to the total number distributed. The research needed a suitably powered sample. Therefore, 500 questionnaires were distributed selected individuals. Of these, 384 valid responses were appropriate for data analysis. Data integrity and reliability were ensured by routinely removing biased and incomplete replies. Structural Equation Modeling (SEM) recommended a sample size of 20 times the number of elements in the research questionnaire. To ensure statistical power and reliability for our research analysis, we used the SEM guideline to get 340 responses to our 17-item questionnaire. This method was used to assure statistical validity and correct representation of the study's variables' linkages and dynamics while retaining statistical power. However, a larger sample is generally better for accurate results (Hair et al., 2019).

3.2 Sample Size Selection Criteria

For data collection, a self-administered survey questionnaire was used (Rada, 2019). The questionnaire's objective was to collect data on the variables identified by the study. The survey contains multiple-choice, free-text, and Likert 5-point scale questions (Douven, 2018). To increase efficiency and accessibility, the survey was administered online. The statistical program SEM-PLS was used to analyze the study's collected data (Lateef, 2023). (Mishra et al., 2019) used descriptive statistics such as means, frequencies, percentages and

standard deviations to characterize the properties of the study variables. The study hypotheses were tested using inferential statistics, including regression, correlation and mediation/moderation analyses (Sand, 2022).

3.3 Criteria for Selecting Sample Size

According to Leguina (2015), it is recommended that the minimum sample size PLS-SEM should be equal to ten times the highest number of structural routes oriented toward a particular construct in the structural model. However, it has been suggested in previous studies (Barroso et al., 2010; Benzidia et al., 2021) that increasing the sample size can enhance the statistical power, precision, consistency, and reliability of estimations conducted using PLS-SEM (Hair et al., 2020). PLS-SEM has been found to exhibit excellent performance when used on datasets with substantial sample sizes, as demonstrated by Hair (2023).

3.4 Time Horizon

The researchers used a cross-sectional survey to acquire study-related data (Philips et al., 2008), and the results were positive. Data was collected from July 2023 to September 2023.

3.5 Statistical Approach

Smart PLS 4 is used for descriptive data analysis. It employs PLS-SEM due to its suitability in analyzing complex relationships in theoretical models with latent variables. PLS-SEM is particularly advantageous when dealing with smaller sample sizes and complex models, offering robustness and flexibility in estimating parameters. To test the proposed relationships, we used PLS-SEM to assess the direct and indirect effects of TA and SLPs on SDGs attainment. By specifying the structural model and assessing path coefficients, we examined how changes in TA and sustainable leadership influenced SDG outcomes. Additionally, we evaluated the significance of mediation effects, providing insights into the underlying mechanisms driving the relationships between variables.

Using the alpha test, the consistency and dependability of research tools were determined. Statistics included tests for multicollinearity, means, standard deviations, frequencies and percentages. By using software, the structural equation model was implemented. In this investigation, the bootstrapping functionality of SMART PLS4 was also used. Following the example set by Lateef (2023), the current study employed SMART PLS4 for statistical analysis. After the measurement model had been developed, the convergent and discriminant validity of the scales was assessed. The objective of convergent validity is to determine if items measure the same concept. The composite reliability and average variance were derived from this. According to Ermawati (2018), acceptable composite reliability (CR) levels exceed 0.70, and average variance extracted (AVE) values exceed 0.50. P-values, t-statistics, confidence intervals and coefficient values were computed to develop a structural model for testing the hypotheses.

3.6 The Justification for Employing PLS in Structural Equation Modeling

SEM uses two approaches to estimate associations: PLS-Measurement Model and PLS-Structural Model. The PLS-Measurement Model and the PLS Structural

Model are the two fundamental components of the PLS statistical method, which is extensively employed in SEM. Evaluating the associations between latent variables and their respective observable indicators is a critical task accomplished with the PLS-Measurement Model, as illustrated in Figure 2. Researchers use this element to assess the extent to which observed variables accurately represent the latent constructs they intend to measure indirectly. It provides a quantitative measure of information by evaluating the dependability and accuracy of latent constructs (Figure 2). As an alternative, the PLS Structural Model examines the causal connections and interrelationships among latent variables using the knowledge obtained from the measurement model. It facilitates hypothesis testing concerning the interrelationships among various latent constructs. This facet of PLS-SEM is indispensable for elucidating the intricate network of connections among latent constructs and ascertaining direct and indirect impacts, as illustrated in Figure 5.

Partial Least Squares (PLS) are an indispensable tool in our studies owing to their versatility and resilience in confronting contemporary research obstacles' intricate and ever-changing characteristics. PLS-SEM provides a practicable and adaptable solution in an era where small sample sizes, non-normal distributions and complex relationships between variables frequently characterize data. It empowers us to confidently analyze data, even in situations where conventional statistical methods are inadequate. Furthermore, its versatility extends to numerous disciplines, including social sciences and data science, promoting interdisciplinary cooperation and research. The flexibility afforded by PLS-SEM in modelling reflective and formative constructs facilitates the advancement and verification of theories, thereby enhancing our comprehension of intricate systems. PLS-SEM facilitates the extraction of significant insights from complex data, enabling us to address contemporary research investigations and practical challenges with inventive resolutions in both academic and applied domains.

4. Data Analysis Interpretation and Discussion

A measuring model in research and statistics shows how latent constructs affect observable indicators. It explains how variables are measured and underpins structural models in psychology, sociology and economics. The approach allows researchers to quantify abstract notions and assess measurement instrument reliability and validity, as illustrated in Figure 2.

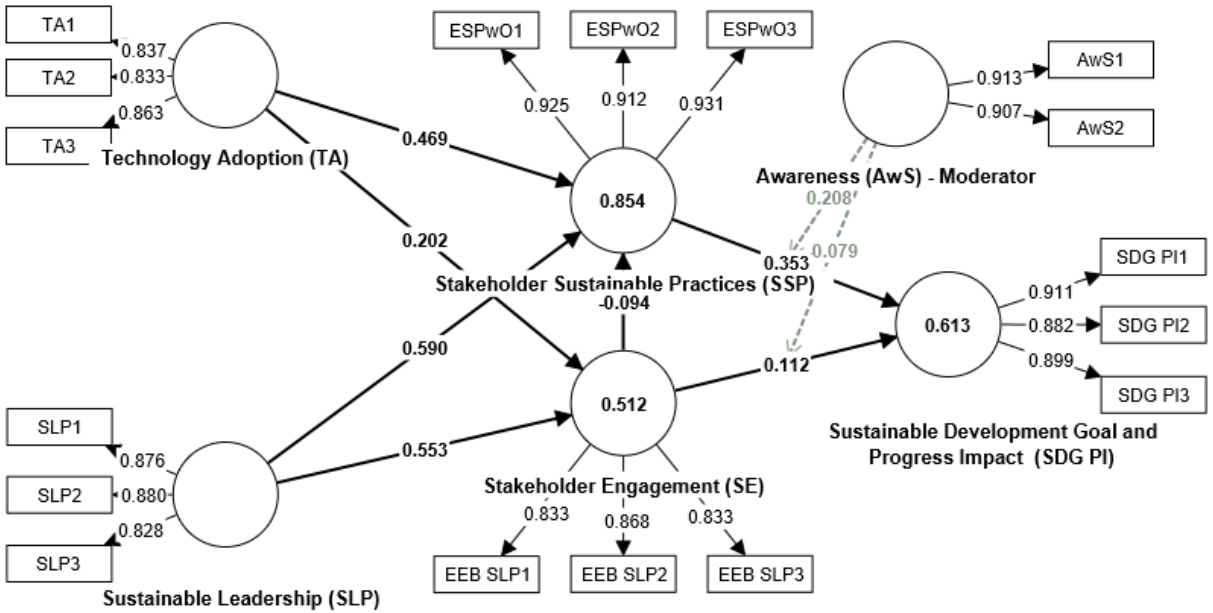

Figure 2: SEM – Measurement Model

Table1: Construct Reliability

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
AWS	0.792	0.793	0.906	0.828
SE	0.806	0.846	0.882	0.714
SSP	0.912	0.914	0.945	0.851
SDG PI	0.879	0.879	0.925	0.805
SLP	0.826	0.827	0.896	0.743
TA	0.799	0.804	0.882	0.713

Discriminant – Validity Fornell-Larcker criterion

AWS	SE	SSP	SDG PI	SLP	TA
0.910					
0.717	0.845				
0.735	0.607	0.922			
0.730	0.595	0.680	0.897		
0.758	0.702	0.871	0.689	0.862	
0.643	0.610	0.847	0.668	0.738	0.844

The following equation for Discriminant Validity: Fornell – Larcker $AVE_i > \max_{j \neq i} r_{ij}^2$

where:

- AVEi is the average variance extracted from the ith construct
- rij is the correlation between the ith and jth constructs
- i and j are indices of different constructs in the model

The results of construct reliability measures, namely Cronbach's alpha, rho_a, rho_c, and AVE for each of the essential constructs investigated in our study, are displayed in Table 1. The reliability measures offer valuable insights into the internal consistency and dependability of the constructs examined in our study. Cronbach's alpha, a commonly employed metric for assessing internal consistency, provides evidence of the reliability of our constructs, exhibiting values that span from 0.792 to 0.912. The numbers above demonstrate good coherence in the data obtained for each construct. Typically, a Cronbach's alpha value of 0.7 is deemed satisfactory, and our findings surpass this established criterion. In addition, the CR metrics, specifically rho_a and rho_c, enhance the strength and resilience of our constructions. The observed values in this study vary from 0.793 to 0.914, suggesting that the constructs under investigation demonstrate a notable level of internal consistency and reliability. The results align with our initial hypotheses, as our objective was to build measures that effectively represent the fundamental nature of the studied variables. The observed AVE values, which range from 0.714 to 0.851, indicate that the constructs under investigation have a significant amount of variance that can be accounted for by the indicators associated with each construct. The assessment of variance explained (AVE) is an essential indicator for validating our constructs' distinctiveness and ability to capture significant variability in the data. Within the given framework, the AVE values we obtained exceed the suggested threshold of 0.5, providing additional support for the convergent validity of our constructs. Hence, the construct reliability measures outlined in Table 1 highlight the strength and consistency of our research constructs. Utilizing these metrics instills assurance in the coherence and dependability of the data gathered for our study, hence validating the robustness of our research methodology and bolstering the legitimacy of our conclusions.

Table 2: F-square matrix & R- Square

	AWS	SE	SSP	SDG PI	SLP	TA	AWS x SSP	AWS x SE	R-square	R-square adjusted
AWS				0.122						
SE			0.029	0.015					0.512	0.510
SSP				0.137					0.854	0.853
SDG PI									0.613	0.608
SLP		0.286	0.849							
TA		0.038	0.663							
AWS x SSP				0.069						
AWS x SE				0.012						

The following equation was used to find the R-Square

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2}$$

where n is the number of observations

- yi is the actual value of the response variable for the ith observation
- y^i is the predicted value of the response variable for the ith observation
- $\bar{y}$ is the mean value of the response variable

In our study, the f-square values offer significant insights regarding the magnitudes of the effects of diverse relationships among key variables. The effect sizes provide insights into the practical implications of our findings that extend beyond mere statistical significance. Significantly, an f-square value of 0.849 indicates that SLP has a substantial effect on SSP, highlighting the critical role that leadership plays in influencing sustainable engagement and practices in academic institutions. On the contrary, the f-square value of 0.029 associated with SE and SDG PI on SDG and quality education suggests a comparatively diminished effect size. This implies that although SE does contribute to SDG PI, its immediate effects might be comparatively restricted. On the other hand, the f-square values of 0.069 and 0.012 for the combined effect of AWS, SSP, and SE as moderators of SDG PI on SDG PI indicate that awareness enhances the impact of stakeholder practices and engagement on SDG 4.

The R-square and adjusted R-square values provide additional evidence that our regression models are robust. The R-square value of 0.854 for SSP suggests that the model accounts for around 85.4% of the observed variability in sustainable practices. Likewise, with an R-square value of 0.613 for SDG PI, our model accounts for approximately 61.3% of the variability observed in the advancement toward achieving the SDGs. The significant R-square values indicate that the selected independent factors effectively explain the observed discrepancies in SSP and SDG PI. In summary, our research emphasizes the critical significance of SSP, TA, and stakeholder dynamics in influencing sustainability practices within academic institutions in Saudi Arabia and making contributions toward the advancement of the SDGs. The nuanced effect sizes and explanatory capacities enhance the comprehensive comprehension of the complex interconnections between these variables. This knowledge is of great value to policymakers, practitioners and scholars who are striving to promote sustainability initiatives in educational environments.

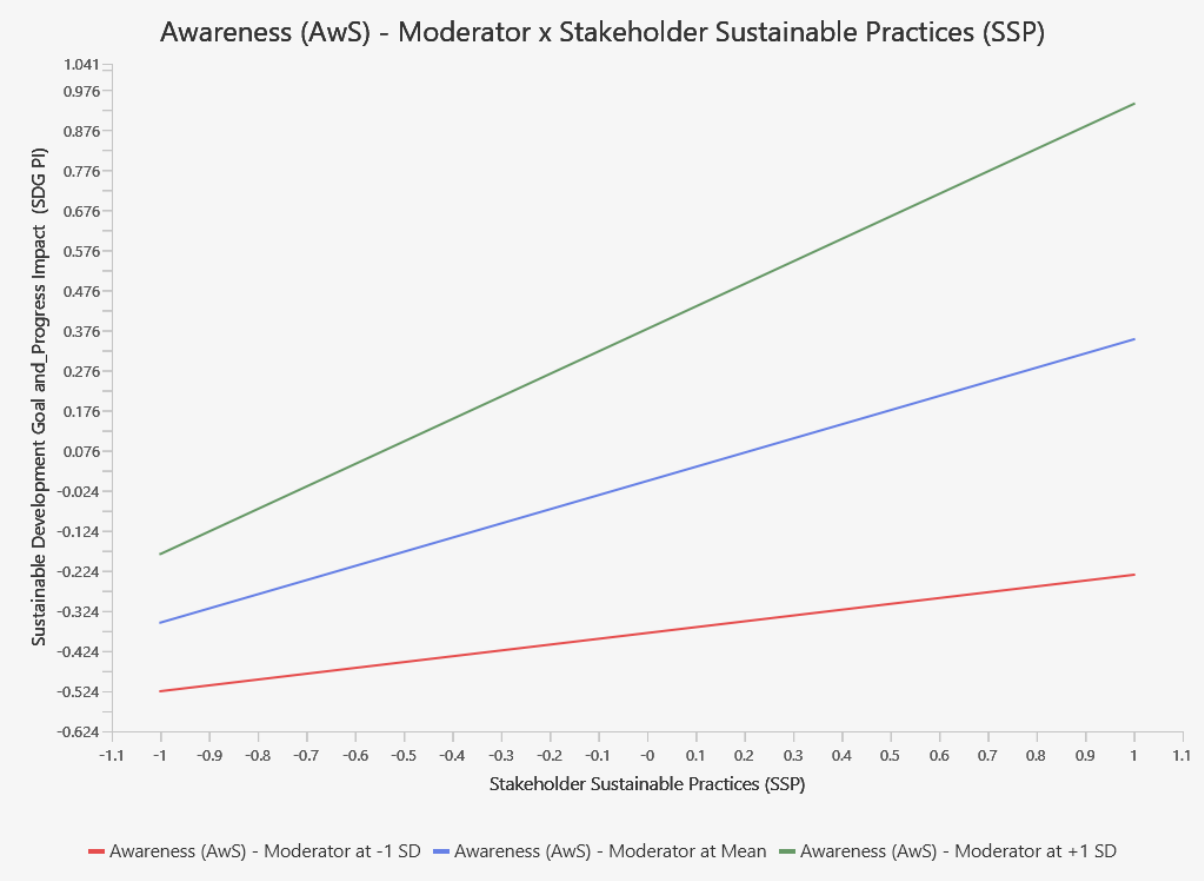

Figure 3: Slope Analysis – Moderation Effect 1

The equation for slope analysis is as follows:

$$\text{Slope} = b_1 + b_3 \times M$$

Where:

- b_1 is the main effect of the independent variable on the dependent variable
- b_3 is the interaction effect of the independent variable and the moderator variable on the dependent variable
- M is the value of the moderator variable

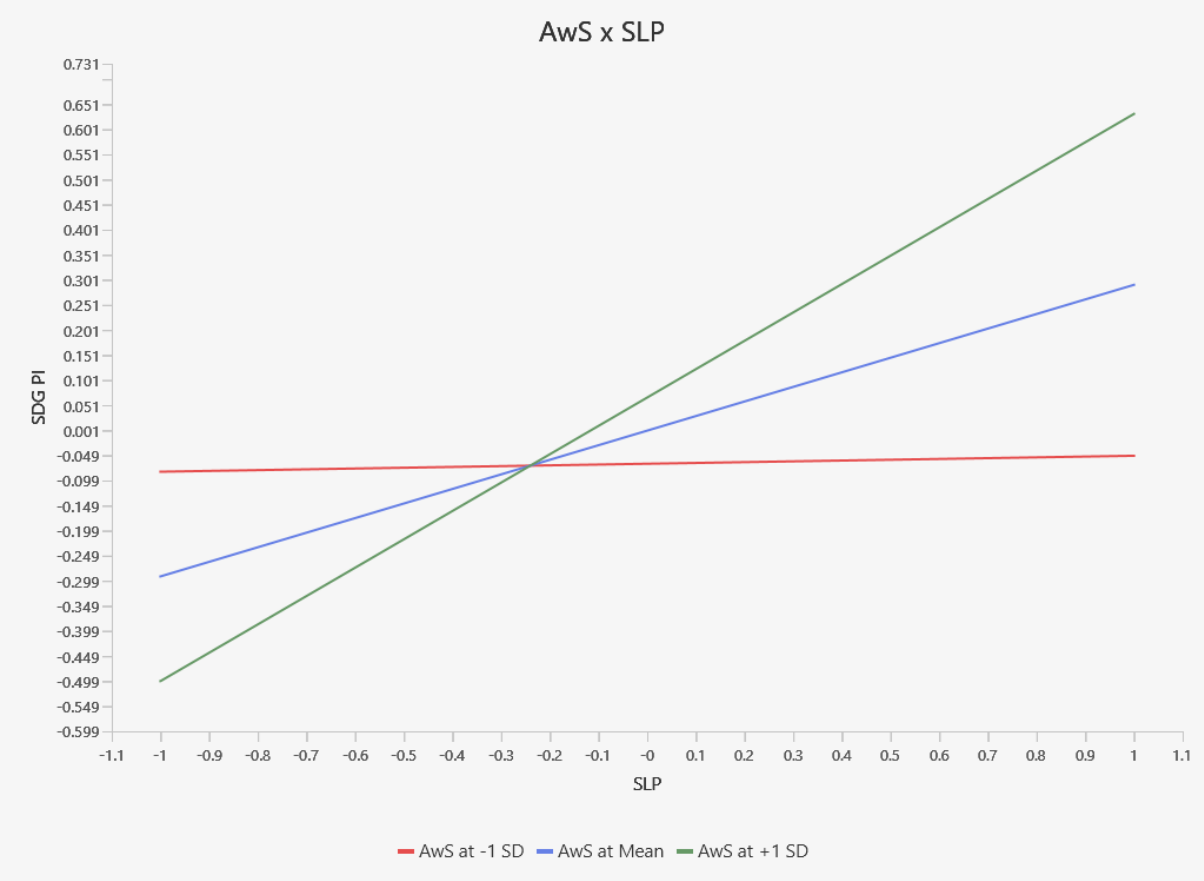

Figure 4: Slope Analysis – Moderation Effect 2

Researchers and statisticians use structural models to show latent construct linkages and interactions. Beyond the measurement model, structural models show causal or correlational paths between variables. By studying these structural links, scholars may grasp complicated dynamics and interdependencies within a conceptual framework and fully understand the events, as indicated in Figure 5.

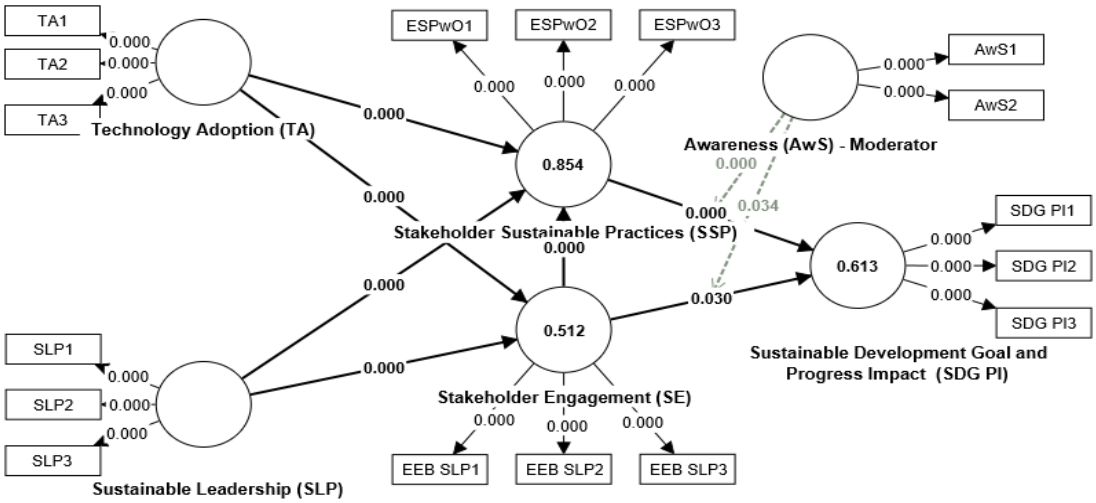

Figure 5: SEM- Structural Model

Table 3: Hypothesis Testing

Hypothesis	Path	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T-statistics (|O/STDEV|)	P-values	Remarks
H1	TA -> SDG PI	0.182	0.180	0.028	6.393	0.000	Supported
H2	SLP -> SDG PI	0.252	0.251	0.034	7.332	0.000	Supported
H3	AWS x TA -> SDG PI	0.208	0.204	0.05	4.181	0.000	Supported
H4	AWS x SLP -> SDG PI	0.275	0.291	0.137	2.000	0.046	Supported

The bootstrapping outcomes obtained with SMART PLS in Table 3 provide insights into the proposed relationships in the hypotheses. The data shows hypothesis testing on the effects of TA, SLP, AWS and their combined impact on SDG PI. All hypotheses were accepted due to their statistically significant t-statistics and low p-values, which support the hypothesized correlations. H1 shows a positive relationship between TA and SDG PI, with a t-statistic of 6.393 and a p-value of 0.000. As technology adoption rises, SDG PI improves; therefore, H1 is acceptable. H2 shows a similar positive correlation between SLP and SDG PI, with a t- statistic of 7.332 and a p-value of 0.000. Again, stronger university sustainable leadership favorably impacts SDG PI. Hence, H2 is acceptable. H3 includes an interaction term, showing that AWS and TA positively affect SDG PI (t-statistic: 4.181, p-value: 0.000). H3 is embraced because stakeholders who are aware of sustainability and employ technology advance sustainability goals. H4 uses a similar interaction term, AWS and SLP. The t-statistic is 2.0. However, the p-value is 0.046, suggesting a slightly significant result. This indicates that knowledge and sustainable leadership may moderately affect SDG PI; hence, H4 is provisionally accepted.

Hence, these findings can help Saudi universities achieve sustainable development. The positive relationships between TA, SLP, and AWS in influencing SDG PI emphasize the importance of strategic technology investments, sustainable leadership and awareness to boost sustainability initiatives. As Saudi universities expand, incorporating these aspects can help them achieve national and global sustainability goals and advance UN socioeconomic and environmental goals.

5. Discussion

Through an extensive examination of existing literature and meaningful interactions with university stakeholders, the study reveals a set of noteworthy findings specifically centered around the circumstances faced by faculty and students in academic institutions. The conclusions are derived from primary data obtained through surveys carried out in Saudi Arabian universities. The report clarifies the direct contribution of sustainable practices among Saudi universities to the achievement of important UN SDGs. More precisely, these findings are strongly related to SDG 4, 7, 8, 9, 10, 12, 13 and 17.

The research highlights a significant and essential correlation between the TA and the SDG PI, particularly about renewable energy and climate action. Saudi universities contribute to the achievement of SDG 7 (Affordable and Clean Energy) and Sustainable Development Goal 13 (Climate Action) by promoting the use of technology (Shobande & Ogbeifun, 2022). Moreover, the study highlights the crucial impact of SLP on improving SDG PI. Universities managed by stakeholders who prioritize sustainability have made significant advancements, especially in promoting responsible consumption. This aligns with the goals outlined in SDG 12 (Responsible Consumption and Production) and SDG 17 (Partnerships for the Goals) (Islam et al., 2017; Khan & Damanhouri, 2017). The complex network of connections within the study also emphasizes the crucial significance of SE and SSP. The study indicates that SE has a minor impact, whereas SSP had a notable effect. This emphasizes the importance of SDG 8 (Decent Work and Economic Growth) and SDG 10 (Reduced Inequalities) in Saudi academic institutions (Saratun, 2016). The research indicates that an enhanced understanding of sustainability among faculties and students influences favorable progress in SDG PI, underscoring the significance of alliances and cooperation (SDG 17) in attaining the SDGs. Ultimately, this study, which relies on firsthand data obtained through surveys from universities and higher academic institutions, plays a crucial role in advancing the UN SDG 4, 7, 8, 9, 10, 12, 13 and 17. These findings give excellent information for Saudi universities to promote sustainable practices and make a substantial contribution to the global sustainability debate.

In addition to the significant findings highlighted in the study, further insights have emerged from the comprehensive examination of existing literature and interactions with university stakeholders. These insights shed light on the multifaceted challenges and opportunities faced by faculties and students within academic institutions, particularly in the context of sustainability initiatives. One noteworthy aspect is the direct contribution of sustainable practices in Saudi universities toward the attainment of key the SDGs. Through the TA and SLPs, academic institutions in Saudi Arabia are actively contributing to SDGs 4, 7, 8, 9, 10, 12, 13 and 17. Precisely, the promotion of renewable energy and climate action, as facilitated by TA, aligns with SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action).

Moreover, the study underscores the pivotal role of sustainable leadership in driving progress toward SDGs. Universities led by stakeholders who prioritize sustainability have demonstrated significant advancements, particularly in promoting responsible consumption (SDG 12) and fostering partnerships for sustainability (SDG 17). This emphasizes the interconnectedness between sustainable leadership and the achievement of various SDGs. Furthermore, the research highlights the importance of SE and sustainability practices in driving sustainable development within academic institutions. While SE alone may have a minor impact, SSPs significantly contribute to SDGs 8 (Decent Work and Economic Growth) and 10 (Reduced Inequalities). This underscores the importance of collaborative efforts and alliances in advancing sustainability agendas.

6. Conclusion

The objective of this study was to investigate the complex correlation between SLP, TA and the achievement of SDGs. By conducting an extensive analysis of existing literature, the research emphasized the increasing acknowledgment of technology's crucial contribution to the advancement of SDGs and the importance of SLP in this particular context. The results of the research confirm that the TA (Kearns, 2011), including programs for digital transformation and renewable energy technologies, has great potential to advance sustainability objectives. Similarly, SLP (Fazlagić & Skikiewicz, 2019), which is defined by its dedication to ethical, enduring and socially accountable strategies, has become a crucial facilitator in the quest for SDGs in academic institutions. The empirical evidence has not only confirmed but also enhanced these conclusions. The findings demonstrate that the deployment of technology has a substantial and positive impact on the SDG PI (Nathaniel et al., 2023). This emphasizes the same feelings expressed in the literature, highlighting the crucial importance of technology in tackling global sustainability concerns. Moreover, our research underscores the pivotal significance of sustainable leadership in facilitating the progress of SDGs. Academic institutions managed by top management level who prioritize sustainability demonstrate outstanding skill in aligning their plans and operations with the SDGs, resulting in beneficial outcomes.

The study explores the complex dynamics within these interactions. Technology adoption continues to influence the advancement of SDGs strongly. However, the impact of stakeholder participation in SLPs is also apparent, although it may vary depending on the individual environment. Moreover, whereas SE and environmental sustainability policies have a statistically significant impact, their combined contribution enhances the understanding of the SDG landscape by introducing additional considerations. The research emphasizes that integrating sustainability awareness into academic operations is a clear catalyst for SDG advancement. This finding aligns with the literature's demand for more understanding and concern for sustainability.

Nevertheless, it also emphasizes the intricate correlation between awareness of sustainability and participation of students and faculties, emphasizing the necessity for a more profound comprehension of these interconnected processes. The study highlights the importance of adopting a comprehensive approach to achieve the SDGs. TA and SLP are essential foundations, while SE and the integration of environmental sustainability strategies enhance the whole experience. Moreover, the awareness of sustainability becomes a powerful driver, promoting a culture of accountability and creativity.

The current study emphasizes that the attainment of SDGs goes beyond technical or management efforts. It involves a thorough and all-encompassing change that includes elements like leadership, technology, culture and involvement. The present study highlights the crucial significance of aligning university practices with the broader sustainability agenda while recognizing the inherent complications that academic institutions may face in doing so. Hence, it is evident that the present study is in line with the fundamental objectives of the SDGs, thereby highlighting the crucial role of leadership,

technology, culture, and engagement in promoting sustainable development, in line with the objectives of SDGs 4, 7, 8, 9, 10, 12, 13 and 17 . By cultivating a more profound comprehension of these interconnections, Saudi universities' engagement and their intricate contextual subtleties, actively contribute to the worldwide endeavor of achieving a sustainable future. This study serves as a connection between the knowledge gained from existing literature and the practical facts, facilitating progress toward a future that is both environmentally sustainable and economically profitable in academia.

Future research in this field could investigate cross-cultural differences in the relationships between SLP, TA and SDG PI, shedding light on how various cultural contexts impact sustainability efforts. In sector-specific studies, the unique challenges and opportunities encountered by industries such as healthcare, finance and manufacturing may be examined in greater depth. Longitudinal analyses monitoring the sustainability journeys of academic institutions over extended periods may reveal evolving patterns and lasting effects. Additionally, it may be of interest to investigate the perspectives of faculties on SLP and TA, as well as the role of government policies in promoting sustainability within academic institutions. Future research must quantify the environmental impact of TA, investigate multi-stakeholder collaborations and focus on strategies for sustainable leadership development. In addition, emerging technologies, sustainable supply chains and cross-regional comparative studies could cast light on innovative routes to achieving the SDGs. This research can ultimately enlighten policy recommendations and best practices for fostering sustainable leadership and TA to advance global sustainability objectives.

Furthermore, the present research highlights several areas for future inquiry. Cross-cultural studies could explore how different cultural contexts influence the relationship between sustainable leadership, TA and SDG progress. Sector-specific analyses might delve into the unique challenges and opportunities faced by industries such as healthcare, finance and manufacturing in implementing sustainability practices. Longitudinal studies could track the evolution of sustainability efforts within academic institutions over time, providing insights into sustainable development trajectories. Additionally, investigations into the environmental impact of TA, strategies for sustainable leadership development, and the effectiveness of multi-stakeholder collaborations offer valuable guidance for policymakers and practitioners alike.

The study has numerous implications for academic institutions and policymakers. In the first place, it emphasizes the importance of TA and sustainable leadership in advancing SDGs in academic institutions. To contribute meaningfully to these global objectives, academic institutions should consider investing in sustainable technologies, nurturing a culture of sustainability, and equipping leaders with sustainable leadership skills. The study also emphasizes the significance of faculty participation in sustainable initiatives. Initiatives that encourage university employees to buy in and participate in sustainability practices can be prioritized by academic institutions. Finally, policymakers can leverage these findings to develop supportive

regulatory frameworks that encourage TA and sustainable leadership within academic institutions, thereby facilitating progress toward SDGs.

The research presented here suggests several critical takeaways for faculties, teachers, students and university leaders within academic institutions. It begins by emphasizing the significance of incorporating sustainability principles into leadership practices. University leaders should align their leadership strategies with sustainability objectives to cultivate a culture of accountability and environmental stewardship. Second, the study encourages stakeholders to consider the strategic incorporation of technology, particularly in areas such as renewable energy and information communication technology, to improve environmental sustainability. Lastly, sustainable leaders can improve stakeholders' engagement toward sustainable practices by fostering an inclusive and supportive workplace that encourages participation in sustainability initiatives.

From a social perspective, the research highlights the potential of TA and SSP to resolve the SDGs' most pressing societal challenges, such as poverty, inequality and environmental degradation. Sustainable practices and technologies can improve living conditions, decrease inequalities, enhance living conditions, decrease inequalities, and increase community access to clean energy and resources. In addition, the study emphasizes the role of stakeholder awareness in promoting sustainable practices and the need for educational and awareness programs to engage society in sustainable development initiatives.

However, this study has significant limitations. Saudi universities' findings may not apply to other countries or institutions. In contrast to cross-sectional studies, longitudinal studies may offer a more dynamic view. Self-reported statistics may be biased by social desirability. While sample size standards were followed, a larger, more diverse sample could improve generalizability. However, self-reported surveys and Likert-scale interpretations may reduce data precision despite proven assessment procedures. Only a little was done to examine economic or policy factors that affected the observed connections. Interpreting and applying the study's conclusions to sustainable higher education requires acknowledging these limitations.

Disclosure statement
There is no potential conflict of interest.

Data Availability Statement
The statistical data used in this research has been shared with the research as a supplementary file.

Declaration
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