TEM Journal. Volume 15, Issue 3, pages 3083-3100, ISSN 2217-8309, DOI: 10.18421/TEM153-88, August 2026.

# Management of Technology Adoption as a Mechanism Linking Quality Education and Sustainability Outcomes in Higher Education

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***Abstract* – Prior research highlights the importance of quality education in advancing sustainability in higher education, yet limited attention has been given to the technological mechanisms through which educational inputs translate into sustainability outcomes. This study examines how quality education influences sustainability-related outcomes and investigates the mediating role of technology adoption and the moderating effect of technology readiness. Drawing on the Unified Theory of Acceptance and Use of Technology (UTAUT), the study hypothesizes that quality education positively affects sustainability awareness, skills, values, decision-making, community engagement, and alignment with the Sustainable Development Goals, with technology adoption serving as a key transmission mechanism strengthened by technology readiness. Using a cross-sectional survey design, data were collected from 1,275 university students in Saudi Arabia and analyzed using SEM-PLS and IPMA. The results indicate that quality education significantly influences all sustainability outcomes, while technology adoption mediates these relationships and technology readiness amplifies adoption effects. Technology adoption emerged as the most important yet least-performing factor.**

***Keywords* – Quality Education, technology adoption sustainability practices, higher education, UTAUT.**

DOI: 10.18421/TEM153-88
https://doi.org/10.18421/TEM153-88

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*Received: 12 December 2025.*
*Revised: 10 February 2026.*
*Accepted: 17 April 2026.*
*Published: 27 August 2026.*



## 1. Introduction

The use of digital technology in education has transformed how educational institutions throughout the world handle, present, and grade information [1], [2]. Information systems and digital infrastructures are becoming more and more important for promoting sustainable education and keeping track of progress toward Sustainable Development Goal 4 (SDG-4) on quality education [3]. In this regard, the readiness of digital infrastructure, the introduction of learning technologies, and the use of analytics to inform decision-making are all important information management behaviors that can be leveraged to integrate the outcomes of education with sustainability practices [4]. However, the study of the impact of technological adoption and institutional readiness on the relationship between educational programs and sustainable practice remains under-researched. To fill this gap, this study employs structural equation modeling, including partial least squares (SEM-PLS), to provide real-life examples of how readiness for information systems and the use of new technologies can contribute to sustainable teaching practices. It contributes to the development of discourse in the information management research sphere and gives valuable insights to policymakers and organizations.

The current study focuses on how the potential of sustainable practices can be nurtured in Saudi Arabian universities using quality education, which is enhanced by the use and adoption of technology. The paper considers quality education as not an aspect of pedagogy but as an information management system, the digital infrastructure, raising awareness, developing skills, values, and community engagement to address the sustainability of practices. It uses the Unified Theory of Acceptance and Use of Technology (UTAUT) [5] and Structural Equation Modeling-Partial Least Squares (SEM-PLS) [6] to study the implications of these factors on sustainability in higher education.

Even though the former study has demonstrated how technology can address knowledge gaps and contribute to sustainability [7] there exists a major limitation in the previous research. To begin with, in some countries, such as Saudi Arabia, where culture and infrastructure factors influence the adoption, nearly no attention has been given to the significance of technology readiness in the education sector [8]. UTAUT has not been extensively applied in the research of the role of education in advancing sustainability practices, even though it has been employed to study the technological acceptance [5]. Additionally, the role of technology readiness as a moderator has not been paid any attention in developing sustainability practices in empowering students to face real-world problems like green innovation and ethical consumerism [9], [10]. To fill such gaps, this paper examines the effect of quality education by designing curriculum, educator training, student-centered learning, and digital literacy in promoting sustainability practices. It analyzes the responses of 1275 Saudi Arabian university students regarding the moderate importance of technology readiness.

The research is guided by the following questions:

- *RQ1: How does quality education raise awareness and build skills for sustainable innovation in technology-infused learning environments?*
- *RQ2: What role does technology adoption play in mediating the relationship between quality education and sustainability outcomes?*
- *RQ3: How does technology readiness influence the integration of sustainability practices into educational frameworks?*
- *RQ4: How can technology-infused education balance traditional pedagogical approaches with innovative tools to enhance sustainability-focused learning outcomes?*

Although the literature on sustainability education is growing, it often overlooks the integration of technology, experiential learning, and accountability. This study proposes a holistic approach by emphasizing digital tools, SDG alignment (refer to Appendix I), experiential practices, and educator training. The study shows how technology readiness affects institutional sustainability practices by using UTAUT [5].

The study assesses mediation and moderation effects using SEM-PLS, which is well-suited for complex reflective-formative models and small or non-normal samples [11].

The results have real-world implications for those working in education, government, and technology. They underline the importance of curriculum, fair technology access, and teachers.

## 2. Literature Review

Theoretical Foundation and Justification for UTAUT: Technology is becoming increasingly significant in education towards sustainability, notably in the realization of Sustainable Development Goal 4, which focuses on inclusive and quality learning. This paper employs the Unified Theory of Acceptance and Use of Technology (UTAUT) to comprehend how the use of technological changes helps in achieving these objectives. UTAUT describes the use of technology by four fundamental components, which include: Performance Expectancy, Effort Expectancy, Social Influence, and Facilitating Conditions. Collectively, these issues provide a holistic picture as to why students and teachers are willing to embrace the use of digital tools, specifically in learning practices where innovation, collaboration, and digital skills are necessary to maintain sustainable practices [12]. The rest of the theory of technology adoption underwent a review, yet none of them applied to the context of the current research. The most popular technology acceptance model (TAM) is based primarily on individual perceptions, whereas little is said about the institutional support or training, or cultural effects, which are significant factors in sustainability education. The Diffusion of Innovations (DOI) theory describes how the idea is diffused in society, but it does not give much understanding of the motivations or barriers of teachers and students to use such technologies as AI or IoT. Social Cognitive Theory (SCT) focuses on the individual learning processes and does not take into consideration the institutional and community-level factors. UTAUT was thus selected since it incorporates individual, interpersonal, and organizational views in one framework. Its predictive power is also high, and thus it is particularly effective in investigating the interaction between Quality Education and Technology Readiness when determining the effects on technology adoption and, ultimately, sustainability findings in Saudi universities. Such a holistic method correlates well with the objective of the research and offers a strong basis for the realization of technology-based sustainability education (Figure 1).

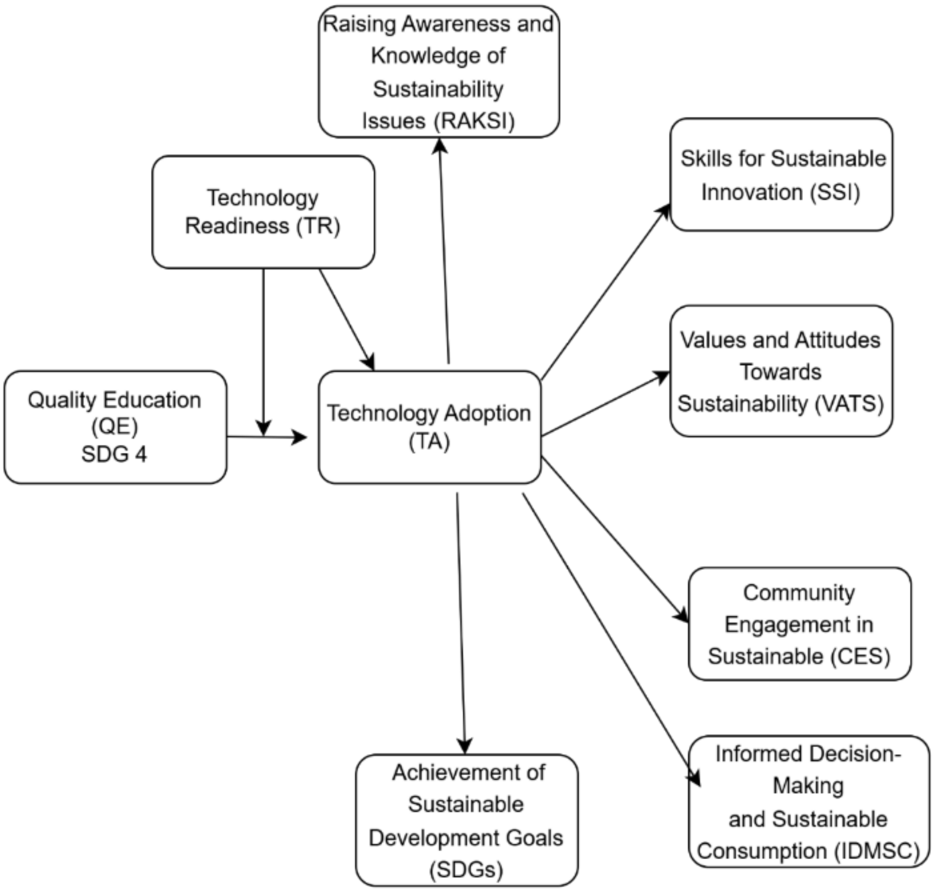


*Figure 1. Framework of the study*

### *2.1. Quality Education*

Quality education, as outlined by SDG 4, is central to fostering sustainable behaviors through well-designed curricula, teacher training, and digital literacy [13], [14]. While its value in raising awareness and building skills is widely acknowledged, integration with technology and hands-on learning still needs improvement. Studies agree that education empowers learners to contribute meaningfully to society [14], [15] and supports inclusive development [16], but the challenge lies in aligning these goals with evolving societal needs. Technological integration and student-centered learning (SCL) are essential for building digital skills and fostering sustainability through active engagement and experiential learning [17], [18]. However, sustainability training and ethical considerations remain underdeveloped, even as tools like AI and IoT begin to enhance education [19], [20]. Educators play a critical role through their attitudes and community engagement [21], [22], yet the lack of comprehensive training limits their impact [23].

Community engagement and parental engagement are also key, especially when supported by technology that enhances communication and promotes shared values [24], [25].

Lifelong learning helps individuals adapt to change and pursue personal and professional goals, but digital inequality poses a barrier [26], [27]. Digital literacy and assessment systems promote critical thinking, collaboration, and sustainability awareness [28], [29], while health-focused education further supports responsible decision-making and community well-being [30], [31]. Overall, while the literature emphasizes the strong link between quality education and sustainability, it also reveals gaps in technology use, educator preparation, and policy integration that must be addressed for real impact.

### *2.2. Raising Awareness and Knowledge of Sustainability Issues*

In the contemporary landscape, it is important that individuals understand and address sustainability challenges through the application of quality education. Knowing about the pros and cons of sustainability refers to the awareness of sustainability.

Previous studies show that incorporating Environmental and Sustainability Education (ESE) in school curricula will help to raise awareness and action [32].

For instance, they contend that environmental literacy, particularly when taught via critical thinking and practical experience, enables students to understand challenging sustainability concerns. Though numerous individuals appreciate this concept, there is still discussion on the best way to teach it. Some studies emphasize teacher training, claiming that improved teacher readiness enables students to acquire the appropriate attitudes and abilities to handle environmental issues [33], [34]. Though they vary in method, these studies all emphasize the need for teacher training. While the other emphasizes what happens in individual classrooms, one examines large-scale changes across whole systems. This indicates that there is still no straightforward answer on which strategy is more effective. There is consensus that students should study methods that span topic borders and include critical thinking. For instance, project-based and problem-based learning are frequently advised as they make education more interesting and practical [35]. However, it is not always clear how well these techniques operate in various educational environments or over the long run. While some studies advocate for making sustainability more engaging and understandable by employing games and hands-on learning [36]. The Study still need knowledge on whether these strategies truly have a long-term impact. Though notably in other cultural or economic settings, further study is required to contrast which approaches function best, even if many studies back these teaching techniques. There are many ideas right now, but not enough data to determine what is most successful. Hence, the following hypothesis is proposed:

*H1: Quality Education significantly impacts raising awareness and knowledge of sustainability.*

### *2.3. Building Skills for Sustainable Innovation*

Different methods are used to teach sustainable innovation in education. Active learning and ESD help students develop problem-solving and future-thinking skills [37], [38], though these studies vary in focus, some stress classroom practice, others focus on broader curriculum design. Working across subjects and with local communities encourages creativity and real-world thinking [39] but it is not always clear how sustainable these efforts are in the long run. Technology and competence-based education can boost engagement and critical thinking [40], [41], yet more research is needed on their long-term impact. Hands-on learning helps students apply their skills to real issues [42], [43], but its effectiveness depends on the learning context.

Finally, teacher training is key; without it, even the best strategies may not work well in [38], [44]. Hence, the following hypothesis is proposed:

*H2: Quality Education significantly impacts building skills for sustainable innovation.*

### *2.4. Promoting Values and Attitudes Towards Sustainability*

By incorporating concepts about sustainability into curricula and teaching sustainable development, quality education shapes sustainability attitudes. Sustainability and education are interconnected holistically [45], [46]. Training educators to enhance sustainability instruction, enhancing students' knowledge, abilities, and attitudes [47]. Transformative learning empowers students to influence sustainability through practical challenges [48]. According to research, sustainable development courses improve environmental and social attitudes. However, educator professional skills development gaps require more excellent training and a curriculum [49]. Educating responsible individuals and promoting environmental literacy promotes global sustainability [50]. Hence, the following hypothesis is proposed:

*H3: Quality Education significantly impacts promoting values and attitudes towards sustainability.*

### *2.5. Fostering Community Engagement in Sustainable Development*

By developing skills, awareness, and cooperation, quality education helps to achieve the Sustainable Development Goals (SDGs). Though they show various ways, several studies stress the need for community engagement. For instance, [51] emphasize how community-based initiatives foster collective action for SDGs 4 and 11, whilst [52] underline the need to match education with local interests for deeper influence. This indicates a movement in sustainability education toward more inclusive, bottom-up solutions. Though there is less discussion on how this manifests in various social or economic settings, [53] relate education to community resilience and stability. Though actual implementation issues are still underexplored, [54] argues that inclusive education can help to lower inequality by reducing it. Though additional study is required to assess long-term results, university-community partnerships also present encouraging examples [55]. Though more study is required to fully grasp how these approaches operate in reality and across different environments, the research generally supports the function of education in community-based sustainability.

Hence the following hypothesis is proposed:

*H4: Quality Education significantly affect community* engagement in sustainable development.

### *2.6. Enabling Informed Decision-Making and Sustainable Consumption*

Studies indicate that quality education is vital for fostering critical thinking and problem-solving abilities, which are essential for informed decision-making in both personal and policy settings [56], [57]. Particularly, sustainability education improves ethical decision-making skills [58] and encourages sustainable consumption by increasing understanding of environmental and social effects [59], [60]. Though these studies highlight the advantages of sustainability-oriented courses, there remains controversy on the best ways to establish enduring sustainable behaviors across various educational levels. Though there is limited data on how these tools affect long-term behavior, digital tools are becoming more and more viewed as a means to include students in sustainable behaviors [61], [62]. Furthermore, although universities are acknowledged for training leaders in sustainability [63], the actual use of sustainable consumption education in higher learning is still underexplored. Access to education gives people the capacity to make sustainable decisions; nonetheless, the difficulty is in guaranteeing that these teachings become practical actions [64]. Fostering sustainable behaviors also depends on experiential learning and community identity building [65], [66]; however, further study is required to know how to properly carry out these projects. Hence, the following hypothesis is proposed:

*H5: Quality Education significantly enabling informed decision-making and sustainable consumption.*

### *2.7. Supporting the Achievement of Sustainable Development Goals (SDGs)*

By encouraging inclusive learning, SDG 4's quality education supports many SDGs. Nigeria's consumer goods industry improves economic development and innovation by teaching needed skills (Saini et al., 2023). Educational programs improve SDG 3 (Good Health and Well-Being) results [67]. Education for Sustainable Development ESD helps SDG 13 (Climate Action) and SDG 15 (Life on Land) by promoting environmental consciousness. Promoting acceptance and equal access promotes societal stability (SDG 16) and gender equality (SDG 5) [53]. Learning throughout life supports personal and professional progress and sustained development [68].

Quality education drives economic growth by equipping individuals with skills for employment and entrepreneurship, as evidenced by its positive impact on GDP per capita, even with challenges in long-term management [67]. It enhances health outcomes by raising awareness and improving access to healthcare, forming a vital part of the education nexus [53]. For instance, integrated early childhood programs in Colombia have demonstrated significant benefits for child development [50]. Furthermore, education fosters social equity and inclusion by addressing gender disparities and providing opportunities for marginalized groups, aligning with the goals of SDG. Hence the following hypothesis is proposed:

*H6: Quality Education significantly affects achievement of Sustainable Development Goals (SDGs).*

### *2.8. Technology Readiness and Technology Adoption*

Technology Readiness and Technology Adoption are critical factors influencing sustainability practices, and a more detailed analysis of them brings to light significant nuances and gaps. The adoption of technology has been indicated to play a direct role in the realization of SDGs, particularly in institutions where digital tools, leadership, and innovation are geared towards achieving a sustainable objective [69], [70]. However, such studies tend to project an assumption that the availability of technology leads to its usage, which is refuted by evidence that community participation is not necessarily improved by technology, where some moderating effects were found to have no significant influence [71]. This implies that social influence is still a more powerful behavioural force than the technology itself, and this is in line with the results of sustainable institutions, where social norms informed adoption more than the systems themselves [72]. Similarly, Technology Readiness is a source of informed decision-making, where the presence of optimism and innovativeness promotes sustainable decisions, but the presence of discomfort and insecurity continues to impede adoption [73], although not many studies delve deeper into how readiness is improved with time or across different cultural contexts. Another advantage of decision support systems is enhanced informed decision-making [74], yet these studies have not investigated how much users trust decision support systems or merely obey them because of institutional pressure.

The awareness of sustainability via technology, aided by campaigns and educational technologies [71], but still depends greatly on the interest and motivational levels of students that are not sufficiently modeled by technology-driven models.

The correlation between technology and expertise to develop sustainable innovation seems to be significant in high-tech and industrial opportunities [75], but they do not directly seem applicable to educational situations with students who have no responsibility or resources. Lastly, even though cultural and organizational factors do affect values and attitudes toward sustainability [76], technology does not play a direct role in this case; technology can assist in creating awareness, but it will not be able to change deeply-rooted values without cultural and institutional reinforcement. The literature in general recommends that Technology Adoption is a potent enabler and not a solution. The use of Technology Readiness as a strength enhancer simultaneously reveals digital disparity and psychological obstacles that numerous researchers do not consider. These restrictions allude to the fact that greater contextual, cultural, and longitudinal studies are required as opposed to assuming that technology always results in sustainability. Hence, the following hypotheses are proposed:

*H7: Technology Readiness moderates the relationship between Quality Education and Technology Adoption.*

*H8: Technology Adoption mediates the relationship between Quality Education and Technology Adoption.*

## 3. Methodology

The quantitative research used in this study investigates how Quality Education affects sustainability practices in higher education and how Technology Adoption mediates, and Technology Readiness moderates the relationship between. Primary data was obtained via a structured questionnaire, based on the adaptation and validated measurement scales used in previous research studies to provide content topicality and quantitative consistency in the methods. Before actual data collection, the instrument was reviewed by academic and industry experts to increase clarity, contextual suitability, and structure and piloted on 15 students to eliminate ambiguity. The responses were measured in terms of a five-point Likert scale that centered to education-related and sustainability-oriented indicators. The research method was the Partial Least Squares Structural Equation Modeling (SEM-PLS) with SmartPLS 4.0 [77] because it can be used to analyze non-normal data, moderate-to-large sample sizes, and complex models with reflective and formative constructs.

SEM-PLS is especially suitable when the research aims at prediction and to analyze formative and reflective hierarchical models where formative indicators characterize constructs, and reflective indicators are used to measure the effects and to be able to analyze the quality of education and sustainability practices on a comprehensive assessment of the measures of construct coherence. The measured model was evaluated by reliability and validity before structural analysis, and internal consistency, convergent, and discriminant validity were ensured before the generation of relationships aimed at testing hypotheses [78]. The methods of multivariate analysis were also used to more effectively estimate the latent constructs and indicators to be observed so that the relationships between the paths and the predictive performance can be robustly interpreted [79]. A combination of purposive and stratified sampling was used to make sampling relevant and representative. The selection of the five Saudi universities, (three public and two private), was aimed at representing various institutional settings. The purposive sampling was used to ensure that we included students who had gone through at least one academic year and were either pursuing business, entrepreneurship, or sustainability-related programs, and a balance between gender, age, and level of degree was maintained using stratification. Out of the 1,500 students that were invited, 1,275 out of them responded validly, thus creating a response rate of 85 percent. The fact that most of the respondents had access to the internet and digital devices is considered when evaluating technology readiness though possible underrepresentation of the rural or low-technology students is also recognized as a weakness. Data collection was done through Google Forms electronically with the help of faculty coordinators. Invitations were sent to randomized lists of potential participants, of eligible students to reduce the self-selection bias since it was not sent to students who had an explicit interest in sustainability or digital technology. The wording of questions was neutral, and screening response patterns were done, and there were no detected abnormalities. Adequacy of the samples was ensured based on the SEM recommendations of having at least 20 responses to an item [80]; since there were 45 measurement items, the necessary minimum of 900 responses was met, and statistical power was high. Data analysis was performed using Confirmatory Factor Analysis (CFA) to provide measurement validity and later using SEM to determine direct, mediating, and moderating relationships among constructs as a combination, giving a holistic and well-integrated evaluation of the proposed research model.

### *3.1. Data Analysis and Interpretation*

The analysis of the data was started by determining the strength of the measurement model with the help of reliability and validity tests, such as Cronbach's alpha, composite reliability, Average Variance Extracted (AVE), and discriminant validity, in accordance with the desirable SEM-PLS instructions [81]. The constructs of all Quality Education, Technology Adoption, and Technology Readiness all had good internal consistency and construct validity. Variance Inflation Factors (VIF) were used to evaluate multicollinearity, and SRMR and NFI as the measurement of global model fit to ensure that the empirical and theoretical models are aligned. SEM-PLS was then used to test structural relationships, which is best used in prediction-based research, non-normal data, and complicated hierarchical constructs [31], [82]. The H1-H6 hypotheses were tested through bootstrapping to get strong significance estimates of the direct effects of quality education on the sustainability outcomes.

The mediation analysis was conducted in two stages based on a formative-reflective approach since sustainability practices were formulated as a higher-order formative construct that comprises of various reflective dimensions, which is in line with the established SEM-PLS processes [83]. These were tested using reflective-reflective moderation logic which was to form an interaction term of Technology Readiness and Quality Education [84], [32]. Also, Importance-Performance Map Analysis (IPMA) was used to determine the constructs that have the most significant effect and performance discrepancies and showed that Technology Adoption is the most problematic but least performing aspect that needs priority intervention [33]. In general, the analysis methodology was capable of direct, mediating, and moderating effects testing, which was consistent with the focus of UTAUT performance expectancy, facilitating conditions, and behavioral enablers [5] (Figure 2).

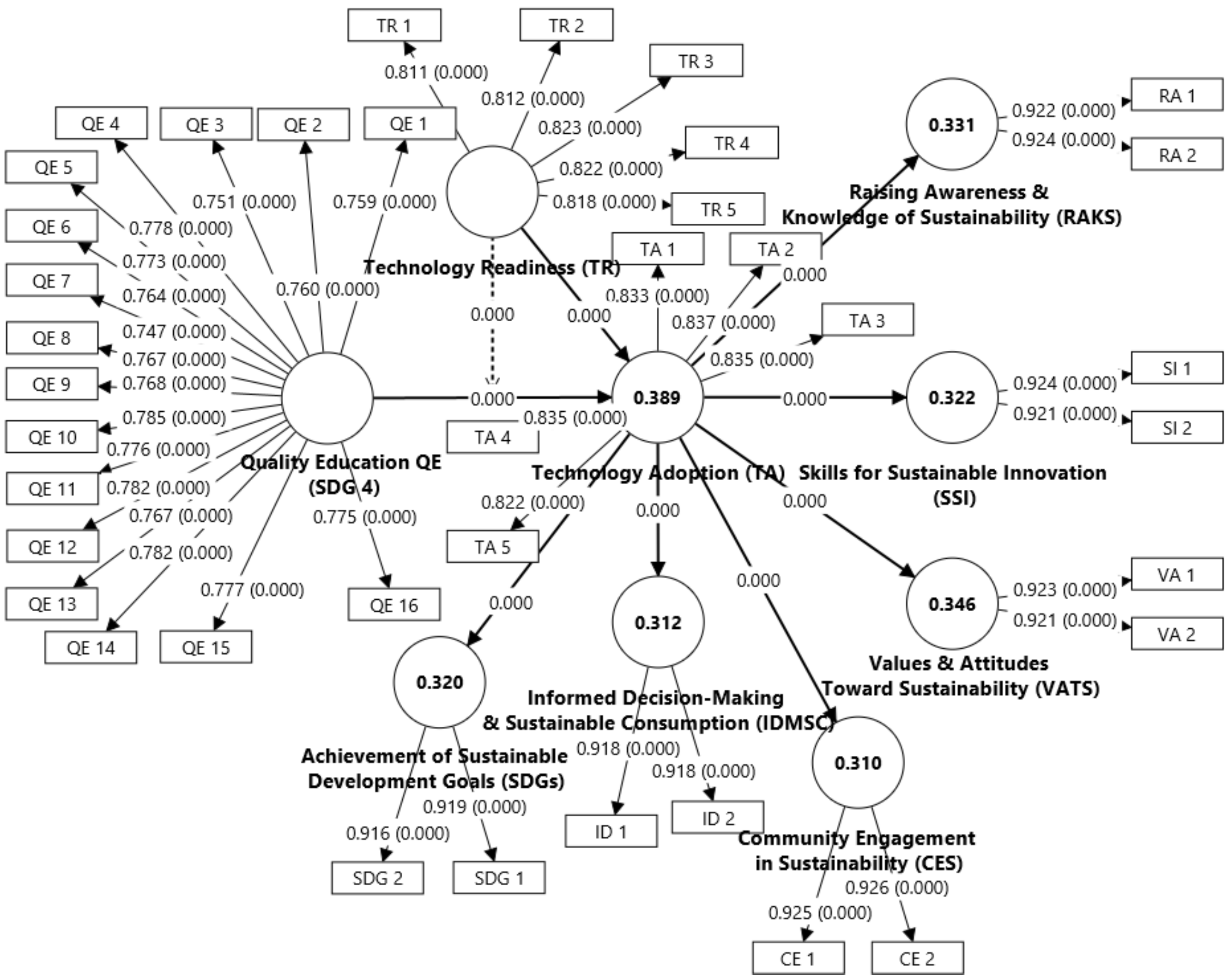


*Figure 2. Measurement model evaluation*

Table 1 presents the construct validity and reliability results, showing that all constructs demonstrate strong internal consistency with Cronbach's alpha, rho_A, and composite reliability values exceeding recommended thresholds.

The Average Variance Extracted (AVE) and √AVE values further confirm adequate convergent and discriminant validity across all constructs.

*Table 1. Construct validity and reliability*

| Construct | α | rho_A | rho_C | AVE | √AVE | ASDG | CES | IDSC | QE | RAKS | SSI | TA | TR | VATS | TR×QE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ASDG | 0.812 | 0.812 | 0.914 | 0.842 | 0.918 | 1.000 | 0.597 | 0.596 | 0.547 | 0.589 | 0.575 | 0.666 | 0.522 | 0.621 | 0.316 |
| CES | 0.833 | 0.833 | 0.923 | 0.857 | 0.926 | 0.597 | 1.000 | 0.602 | 0.538 | 0.597 | 0.587 | 0.647 | 0.498 | 0.614 | 0.287 |
| IDSC | 0.813 | 0.813 | 0.915 | 0.843 | 0.918 | 0.596 | 0.602 | 1.000 | 0.551 | 0.576 | 0.588 | 0.656 | 0.519 | 0.630 | 0.278 |
| QE | 0.954 | 0.954 | 0.959 | 0.592 | 0.770 | 0.547 | 0.538 | 0.551 | 1.000 | 0.524 | 0.524 | 0.534 | 0.556 | 0.554 | 0.049 |
| RAKS | 0.826 | 0.826 | 0.920 | 0.852 | 0.923 | 0.589 | 0.597 | 0.576 | 0.524 | 1.000 | 0.598 | 0.671 | 0.496 | 0.586 | 0.278 |
| SSI | 0.826 | 0.826 | 0.920 | 0.852 | 0.923 | 0.575 | 0.587 | 0.588 | 0.524 | 0.598 | 1.000 | 0.663 | 0.517 | 0.618 | 0.290 |
| TA | 0.889 | 0.889 | 0.919 | 0.693 | 0.833 | 0.666 | 0.647 | 0.656 | 0.534 | 0.671 | 0.663 | 1.000 | 0.549 | 0.686 | 0.316 |
| TR | 0.876 | 0.876 | 0.910 | 0.668 | 0.817 | 0.522 | 0.498 | 0.519 | 0.556 | 0.496 | 0.517 | 0.549 | 1.000 | 0.510 | 0.045 |
| VATS | 0.825 | 0.825 | 0.919 | 0.851 | 0.922 | 0.621 | 0.614 | 0.630 | 0.554 | 0.586 | 0.618 | 0.686 | 0.510 | 1.000 | 0.306 |
| TR×QE | — | — | — | — | — | 0.316 | 0.287 | 0.278 | 0.049 | 0.278 | 0.290 | 0.316 | 0.045 | 0.306 | 1.000 |

Table 1 represents the reliability results, showing that all constructs in the model have strong internal consistency, with Cronbach's alpha, rho_A, and composite reliability values all well above the recommended threshold of 0.70. This means the items used to measure each construct are stable and reliable. The AVE values for all constructs are also above 0.50, indicating good convergent validity, each construct explains more than half of the variance of its indicators as shown in Figure 2. The square root of AVE (√AVE), shown on the diagonal, is consistently higher than all of the correlations in its row and column. This confirms that each construct is more strongly related to its own indicators than to other constructs, demonstrating solid discriminant validity.

Across the HTMT values (off-diagonal entries), all relationships fall below the 0.85 threshold, which further supports that the constructs are distinct from one another and do not measure the same underlying concept. Technology Adoption (TA) exhibits the strongest correlations with other constructs such as VATS, IDSC, and RAKS, which is expected because adoption of technology naturally influences sustainability behaviors and outcomes.

Table 2 reports the robustness of the measurement model, indicating satisfactory explanatory power, acceptable multicollinearity levels (VIF), and adequate overall model fit indices. The post hoc power analysis further confirms that the model has sufficient statistical power to reliably detect the hypothesized relationships.

*Table 2. Measurement model robustness assessment*

| Construct / Path | $R^2$ | $R^2$ Adj. | VIF | Model Fit (Sat./Est.) | Post Hoc Power (α = 1%) | Post Hoc Power (α = 5%) | Remarks |
|---|---|---|---|---|---|---|---|
| Achievement of SDGs (ASDG) | 0.320 | 0.320 | SDG1–SDG2: 1.877 | SRMR: 0.026 / 0.093 | 1.000 | 1.000 | Strong predictive power: TA ->ASDG path is fully powered with 1.000, meaning zero risk of Type II error. VIF normal |
| Community Engagement (CES) | 0.310 | 0.310 | CE1–CE2: 2.035 | d_ULS: 0.513 / 6.368 | 1.000 | 1.000 | Moderate $R^2$; TA -> CES path shows full power, confirming a robust effect. VIF normal |
| Informed Decision-Making (IDSC) | 0.312 | 0.311 | ID1–ID2: 1.887 | d_G: 0.405 / 0.542 | 1.000 | 1.000 | Good $R^2$; TA -> IDSC path fully powered, ensuring detectable effect. VIF normal |
| Raising Awareness (RAKS) | 0.331 | 0.331 | RA1–RA2: 1.982 | Chi-square: 6688.747 / 8532.778 | 1.000 | 1.000 | Highest $R^2$ among DVs; TA -> RAKS path has perfect power, confirming its strength. VIF normal |
| Skills for Sustainable Innovation (SSI) | 0.322 | 0.322 | SI1–SI2: 1.978 | NFI: 0.889 / 0.858 | 1.000 | 1.000 | Good $R^2$; TA -> SSI path fully powered, verifying reliable detection. VIF normal |
| Values & Attitudes (VATS) | 0.346 | 0.345 | VA1–VA2: 1.968 | — | 1.000 | 1.000 | Strong $R^2$; TA -> VATS path fully powered, stable effect. VIF normal |
| Technology Adoption (TA) | 0.389 | 0.388 | TA1–TA5: 2.05–2.22 | — | QE -> TA: 1.000TR -> TA: 1.000TR× QE -> TA: 1.000 | 1.000 | Highest $R^2$ overall; all three predictors have full statistical power, indicating robust mediation and moderation pathways. VIF normal |
| Quality Education (QE) | — | — | QE1–QE16: 2.03–2.33 | — | QE -> TA: 1.000 | 1.000 | No multicollinearity; strong path to TA with perfect power. |
| Technology Readiness (TR) | — | — | TR1–TR5: 1.92–2.05 | — | TR -> TA: 1.000 | 1.000 | Indicators stable; TR significantly predicts TA with full power. |
| Interaction Term (TR × QE) | — | — | 1.000 | — | 1.000 | 1.000 | Full power achieved; the moderation effect is reliably detected despite typically requiring larger samples. |

The quality of measurement is strong in all constructs as shown in Table 2. The results of reliability indicate that the measure of Cronbach alpha, rho A and composite reliability of all the measures are greater than the recommended level of 0.70, which supports the internal consistency and reliability of the measurement.

Convergent validity is established, since the values of Average Variance Extracted (AVE) exceed 0.50 of all constructs, i.e., each construct is more than half the variance of its indicators. The existence of discriminant validity is well defined: The square root of AVE (AVES) of each construct exceeds its correlations with others and all the HTMTs are under the conservative level of 0.85, which proves that two constructs are conceptually different.

Technology Adoption, as would have been expected, has the most significant correlations with sustainability-related outcomes which include values and attitudes (VATS), informed decision making (IDSC), and sustainability awareness (RAKS), as it is at the center of behavior that drives sustainability.

The structural model has a moderate or strong explanatory power with the $R^2$ values of 0.31 to 0.39 in the dependent variables. Technology Adoption is the explained variable with the highest variance ($R^2$ = 0.389) and thus proves to be the most strongly predicted in the model. The values of the Variance Inflation Factor (VIF) are not greater than 2.3 in all the paths, which means there is no multicollinearity.

The model fit measures (SRMR, d_ULS, d G, NFI and chi-square) are within acceptable ranges of PLS-SEM, which proves the suitability of the model structure. The full statistical power (1.000) of all paths at 1% and 5% level of significance, including the interaction effect (TR × QE) suggests that the full procedures of the analysis have reliably identified all the effects.

Table 3 summarizes the hypothesis testing results, indicating that all proposed direct, mediating, and moderating hypotheses are statistically supported with significant path coefficients. These findings confirm the positive effects of quality education on sustainability outcomes and the critical mediating role of technology adoption, strengthened by technology readiness.

*Table 3. Hypothesis testing*

| | Hypotheses | Paths | O | M | STDEV | t-value | p-value |
|---|---|---|---|---|---|---|---|
| Direct | H1 | QE -> RAKS | 0.185 | 0.185 | 0.013 | 14.593 | 0.000 |
| | H2 | QE -> SSI | 0.183 | 0.183 | 0.012 | 14.744 | 0.000 |
| | H3 | QE -> VATS | 0.189 | 0.189 | 0.013 | 14.795 | 0.000 |
| | H4 | QE-> CESD | 0.179 | 0.179 | 0.012 | 14.487 | 0.000 |
| | H5 | QE -> IDMSC | 0.18 | 0.18 | 0.012 | 14.473 | 0.000 |
| | H6 | QE-> ASDG | 0.182 | 0.182 | 0.012 | 14.639 | 0.000 |
| Moderating | H7 | TR x QE -> TA | 0.277 | 0.276 | 0.016 | 17.241 | 0.000 |
| Mediating | H8 | QE->TA -> Sustainability Practices | 0.243 | 0.243 | 0.015 | 15.921 | 0.000 |

The findings as shown in Table 3 indicate that all the direct hypotheses (H1-H6) are highly supported, and Quality Education positively influences sustainability-related outcomes (awareness, H1; skills, H2; values, H3; community engagement, H4; informed decision-making, H5; and SDG achievement, H6). Though these effects are moderate (β 0.18 -0.19), this is also consistent with UTAUT, which says that educational inputs in themselves will not assure behavioral outcomes unless the technology is accepted and used before full benefits can be realized.

The moderating effect in H7 indicates that technology readiness has a very significant enhancement effect on the role of Quality Education on Technology Adoption (β= 0.277). This is a direct reflection of the value of UTAUT to the user preparedness, confidence, and enabling conditions in the development of technology use. Students who are more ready and familiar with digital tools are more apt to adopt them, even with high-quality education levels. Mediating effect (H8) proves that education is the most important pathway of influence of Technology Adoption on sustainability practices (β= 0.243).

This is exactly consistent with the fundamental assumption of UTAUT, which holds that real usage of technology is what transforms favorable environments into reality performances. These other theories, like the Transformative Learning and Experience Learning theories, assist in explaining why education or awareness, values, and skills are developed; however, UTAUT offers the best explanation for why the need to adopt technology is necessary in transforming these educational endeavors to measurable sustainability outcomes. In general, the results confirm all the hypotheses (H1-H8) and point to the fact that Quality Education is the fuel, Technology Adoption, facilitated by UTAUT, is the driver that leads towards sustainability impact.

Table 4 presents the IPMA results, showing that technology adoption has the highest importance but the lowest performance, indicating a critical gap requiring priority intervention. In contrast, quality education and technology readiness exhibit moderate importance and performance, suggesting supportive but secondary roles in enhancing sustainability outcomes.

*Table 4. IPMA map analysis*

| Construct | Importance (Coeff.) | Performance | Gap = (100 – Performance) × Importance | Remarks |
|---|---|---|---|---|
| Technology Adoption (TA) | 0.730 | 48.023 | 37.90 | Highest importance and biggest gap -> Top priority for improvement |
| Quality Education (QE – SDG 4) | 0.243 | 48.259 | 12.58 | Moderate importance and moderate gap -> needs improvement but not urgent |
| Technology Readiness (TR) | 0.213 | 48.346 | 11.02 | Lower importance and moderate performance -> Low–medium priority |

The IPMA (Table 4) and illustrated in Figure 3, provides valuable information on the areas that need the greatest consideration to enhance the practice of sustainability in Saudi universities. The greatest importance (0.73) and weighted gap (37.90) (largest) indicate that technology adoption is the factor that has the greatest impact on sustainability outcomes, but is the lowest performer at the moment. This result is extremely important in the framework of this paper, which is based on UTAUT. UTAUT stresses that the real use of the system is not the intention or the readiness, but the actual use, which is the most important factor of performance. The technology adoption gap is quite considerable, signifying that, even though students appreciate digital tools and know their potential, they do not have them in use to an extent that will produce a meaningful sustainability effect. This confirms that more training is required, ease of use in systems, facilitating conditions, and conducive digital environments.

Quality Education (gap = 12.58) is of moderate importance, and performance shortfall is medium. This implies that although curriculum design, digital literacy, and teacher practice are aspects that lead to sustainability results, the impact is not achieved fully until students utilize technology. This agrees with the argument of UTAUT that educational input is not enough unless it is enhanced by continuous technological adoption. The comparatively narrow distance shows that the educational systems are already working well and, nevertheless, they still need improvements, especially regarding the incorporation of experiential and technology-based learning exercises.

Technology Readiness has the lowest gap (11.02), which means that the students are psychologically ready and have no doubts about using technology. Nevertheless, its score on importance is lower, indicating that readiness alone is not sufficient to initiate sustainability results without its actual implementation. This once again is congruent with UTAUT: preparation determines the intention; however, use behavior (Technology Adoption) is the actual performance driver. The narrow divide is also an indication that universities have effectively developed positive inclinations toward technology, yet they must convert the caution into frequent, substance use.

In general, the IPMA analysis points to one important fact that is relevant to the current study: the greatest obstacle to sustainability practices is not the readiness or the quality of education, but rather the lack of technology adoption, despite it being the most significant predictor of sustainability outcomes. This helps in aligning the theoretical context of the study to the UTAUT perspective and offers a clear roadmap of what institutional change should embrace- the center should be on how to provide an environment where students are not only willing to do it but also continuously engage digital tools to facilitate the sustainability-driven learning and behaviour. To better understand how the three core constructs (TA, QE, TR) align with relevant SDGs, an Importance–Performance–based SDG integration table was developed.

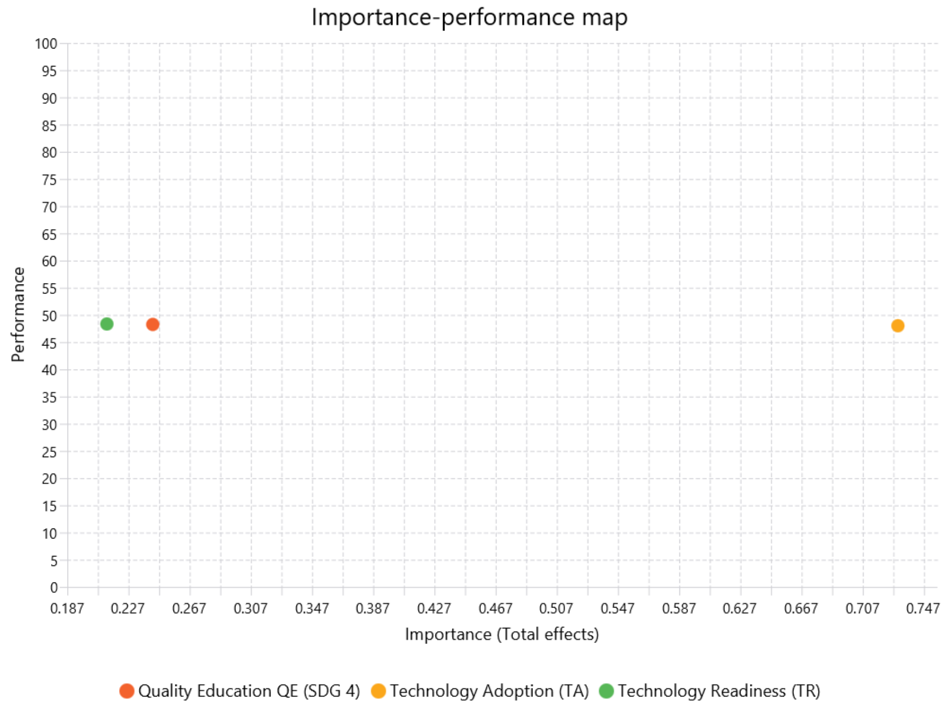


*Figure 3. IPMA – map analysis*

## 4. Discussion

The study findings indicate that Quality Education (SDG 4) has a very strong positive contribution to sustainability awareness, skills, values, decision-making, community engagement, and SDG alignment of students, but the effect sizes are moderate. This reinforces previous studies indicating that traditional learning is not often a sufficient solution to sustainable behavioral change unless accompanied by the effective use of experiential, technology-mediated learning [13], [14]. The sustainability education research also emphasizes that classroom education leads to the growth of awareness and attitudes, whereas more profound change in behaviors is necessary with practice-based and online assistance [32], [33]. These trends are corroborated by the results of the present study, indicating that Quality Education is an essential basis, but it is not always converted into practice. Rather, Technology Adoption proved to be the most useful predictor, which makes sense in accordance with the UTAUT model that states that real use of technology, rather than intention, or readiness, is the factor that will provoke performance results in school [12]. This is also backed by the recent studies, which point to the fact that AI tools, digital dashboards, and e-learning platforms promote sustainability learning in a significant manner only when students actively use these tools [1], [20].

The high level of moderating Technology Readiness supports the previous studies that indicated that psychological confidence, digital optimism, and comfort with technology have a strong impact on the adoption behavior [80], [81]. While carrying out research in the Saudi context, it has been demonstrated that the efforts aimed at digital transformation are not enough when students themselves are not ready to use new technologies [4]. The current research fulfills this gap: Despite the presence of digital infrastructures, their uptake is low unless they are ready. The analysis of IPMA also indicated that the greatest performance gap is Technology Adoption, which indicates that students are not utilizing technology as much as the sustainability of education needs them. It is consistent with the literature that knowledge is not the only requirement of sustainable behavior, and digital interaction, practical implementation, and system-level support are also necessary [39]. Taken together, the results enrich the existing body of knowledge by illustrating that technology adoption is the missing link that turns the quality of the educational process into actionable sustainability behaviors. Although previous researchers knew that Quality Education is important, hardly any of them empirically proved that adoption is the decisive factor, which is evidently shown in this research.

### *4.1. Implication of the Study*

This study highlights that achieving meaningful sustainability education is not only about providing digital infrastructure, but about ensuring effective technology adoption and readiness among students and educators. It demonstrates that digital readiness strengthens the link between quality education and sustainability outcomes, making technology a strategic enabler of SDG-oriented learning rather than just a supportive tool. Overall, the findings emphasize the need for policy, theory, and practice to align around technology-enabled experiential learning for sustainable development.

#### *4.1.1. Policy Implications*

The findings indicate that policy efforts should move beyond merely providing digital infrastructure toward ensuring meaningful technology adoption for sustainability learning. National and institutional SDG 4 strategies should explicitly incorporate digital readiness and confidence-building initiatives for both students and educators, as technology readiness significantly strengthens educational outcomes. Policymakers should also invest in continuous teacher training in AI, learning management systems, and e-learning tools, while revising curricula to emphasize experiential, technology-enabled sustainability learning through simulations, dashboards, and applied projects. Furthermore, ensuring equitable access to digital resources is essential, as digital inequality undermines readiness and adoption. Universities should align their performance indicators with actual digital engagement and sustainability competencies rather than focusing solely on infrastructure availability.

#### *4.1.2. Theoretical Contributions*

This study makes several theoretical contributions by extending the UTAUT framework into the domain of sustainability education. It demonstrates that technology adoption acts as a mediating mechanism linking quality education (SDG 4) to sustainability outcomes, thereby positioning education as both a pedagogical and digital system. The findings also establish technology readiness as a significant moderating factor that amplifies the effectiveness of educational interventions - an aspect that remains underexplored in sustainability and SDG-focused research. Additionally, the results align with service-dominant logic by showing that digital technologies function as value co-creation mechanisms, enabling deeper engagement and the translation of sustainability knowledge into behavior.

#### *4.1.3. Practical Implications*

From a practical standpoint, the study suggests that universities should prioritize structured digital literacy and readiness programs to enhance students' confidence and willingness to adopt technology. Integrating AI tools, learning management systems, and interactive digital resources into coursework can facilitate the practical application of sustainability knowledge. Sustainability-oriented activities should be embedded within digital learning environments using dashboards, gamified systems, simulations, and emerging technologies such as IoT and VR. Institutions should also monitor actual technology usage to identify adoption gaps and refine support strategies, while strengthening university–community–industry partnerships to address real-world sustainability challenges through technology-enabled experiential learning.

### *4.2. Future Avenues of Research*

Future research should examine discipline-specific variation in technology adoption by comparing sustainability learning outcomes across fields such as business, engineering, and health sciences, as the present study relied on a general student sample. Experimental or quasi-experimental designs are also needed to test digital readiness interventions, where structured training programs are introduced to assess their causal impact on technology adoption and sustainability outcomes.

To strengthen behavioral validity, future studies should measure actual technology use by integrating learning management system log data, platform analytics, and AI usage records rather than relying solely on self-reported perceptions. Research should further explore the role of educator digital competence by incorporating constructs such as instructor digital readiness and pedagogical support, which may shape students' adoption behavior and sustainability practices.

Additionally, technology adoption should be disaggregated into specific technology types, allowing researchers to compare the relative effectiveness of AI tools, LMS platforms, simulations, and IoT dashboards in driving sustainability learning. Extending the model to include institutional-level moderators such as digital maturity, ICT policies, and funding support, would provide a more holistic understanding of contextual influences.

Longitudinal designs are recommended to capture dynamic changes in awareness and sustainable behavior over time, overcoming the limitations of cross-sectional data.

Future research should also examine socio-cultural and psychological factors, including collectivist norms, digital anxiety, motivation, and self-efficacy, particularly within Arab and Gulf higher education contexts.

Finally, comparative analyses between public and private universities would clarify whether governance structures condition the education–technology–sustainability pathway.

## 5. Conclusion

The paper has analyzed the role of Quality Education (SDG 4), Technology Readiness, and Technology Adoption on the sustainability practices of Saudi Arabian university students. The results give more than enough evidence that Quality Education positively impacts awareness, skills, values, decision-making, and engagement regarding sustainability, but these direct impacts are of intermediate magnitude. This suggests that education in and of itself, notwithstanding being a prerequisite, does not necessarily lead to sustainable behavior. Rather, the findings establish the role that Technology Adoption is the most effective pathway, which transforms educational input to sustainability outcomes, with the most significant influence on all indicators of sustainability. To make the education about sustainable behavior have a substantial impact, students need to employ technology but not simply have access to it.

Technology Readiness was also observed to be a strong moderator as it multiplied the effect of Quality Education on Technology Adoption. Educational interventions are more beneficial to the students who are more digitally confident, optimistic, and comfortable with technology. This is a crucial point that should be made: digital preparedness is as essential as the development of quality curricula. The joint results prove the case, sustainability education is an effective one when combined with technology-based education and digital competence among students, particularly in such a swiftly digitalizing educational system like Saudi Arabia.

Overall, the research offers empirical support to a technological mediated model of sustainability education, that Quality Education is the foundation, Technology Readiness is the capacity, and Technology Adoption is the actual action to take. Such perspectives can be used to implement SDG 4 and provide practical solutions to improve on sustainability-oriented education in the area.

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*Appendix I*

| Construct | Item Code | Questionnaire Item | Citation |
|---|---|---|---|
| **Quality Education (SDG4)** | QE1 | My courses help me understand key sustainability concepts. | [32] |
| **QE** | QE2 | Teaching methods encourage me to think critically about sustainability issues. | [14] |
| **QE** | QE3 | I am encouraged to evaluate real-world sustainability problems. | [13] |
| **QE** | QE4 | Digital tools in my courses support sustainability learning. | [18] |
| **QE** | QE5 | Instructors effectively use technology to teach sustainability topics. | [14] |
| **QE** | QE6 | I receive adequate support from teachers for sustainability learning. | [21] |
| **QE** | QE7 | My education develops problem-solving skills for sustainability challenges. | [15] |
| **QE** | QE8 | Learning activities strengthen my innovation skills for sustainability. | [37] |
| **QE** | QE9 | My education shapes my awareness of environmental responsibility. | [14] |
| **QE** | QE10 | I understand sustainability's importance through classroom learning. | [13] |
| **QE** | QE11 | Hands-on activities help me apply sustainability concepts. | [36] |
| **QE** | QE12 | My university encourages participation in sustainability initiatives. | [25] |
| **QE** | QE13 | My education builds my digital literacy for sustainability tasks. | [28] |
| **QE** | QE14 | Assignments increase my understanding of sustainability. | [29] |
| **QE** | QE15 | My courses promote responsible and sustainable consumption. | [30] |
| **QE** | QE16 | My education empowers me to contribute to SDGs. | [16] |
| **Technology Readiness (Moderator)** | TR1 | I feel confident using new technologies in my studies. | [84] |
| **TR** | TR2 | I enjoy trying out new digital learning tools. | [84] |
| **TR** | TR3 | I feel comfortable using technology for sustainability-related tasks. | [84] |
| **TR** | TR4 | I do not feel anxious when required to use unfamiliar technologies. *(Reverse coded)* | [84] |
| **TR** | TR5 | I am optimistic that technology improves my learning outcomes. | [84] |
| **Technology Adoption (Mediator)** | TA1 | I regularly use technology platforms provided by my university. | [5] |
| **TA** | TA2 | I use digital tools to access sustainability-related materials. | [20] |
| **TA** | TA3 | Technology helps me apply sustainability concepts in my coursework. | [5] |
| **TA** | TA4 | I prefer technology over traditional methods for sustainability learning. | [20] |
| **TA** | TA5 | Using technology has improved my sustainability-related skills. | [12] |
| **Raising Awareness & Knowledge (RAKS)** | RAKS1 | My education has increased my awareness of sustainability issues. | [32] |
| **RAKS** | RAKS2 | I have gained knowledge about environmental and social challenges. | [33] |
| **Skills for Sustainable Innovation (SSI)** | SSI1 | My education enhances my skills to create sustainable solutions. | [38] |
| **SSI** | SSI2 | I can think innovatively about sustainability issues. | [37] |
| **Values & Attitudes Toward Sustainability (VATS)** | VATS1 | I value sustainable living due to my education. | [47] |
| **VATS** | VATS2 | I have a positive attitude toward sustainability initiatives. | [47] |
| **Community Engagement in Sustainable Development (CESD)** | CESD1 | My education encourages me to participate in community sustainability projects. | [39] |
| **CESD** | CESD2 | I collaborate with others on sustainability activities. | [55] |
| **Informed Decision-Making & Sustainable Consumption (IDMSC)** | IDMSC1 | I make environmentally responsible decisions because of my education. | [59] |
| **IDMSC** | IDMSC2 | I evaluate sustainability impacts before making choices. | [58] |
| **Achievement of SDGs (ASDG)** | ASDG1 | My education helps me understand the Sustainable Development Goals (SDGs). | [39] |
| **ASDG** | ASDG2 | I feel capable of contributing to SDG initiatives in the future. | [64] |