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Smartphone Use and Environmental Sustainability Awareness and Practices Among Students of Al Ain University: A Cross-Sectional Correlational Study

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Abstract

The purpose of this study is to examine the impact of the use of smartphones on the students' environmental awareness and the adoption of environmental sustainability practices at the University of Al Ain. A descriptive analytical approach was used and a questionnaire was employed to gather data from a voluntary non-probability sample of 90 students from different academic programs at the university. The research focuses on five main areas: students' environmental sustainability awareness, perceived positive uses of smartphones, perceived negative environmental consequences of smartphone use, the association between smartphone use and sustainable practices, and suggestions for improving smartphone-supported environmental sustainability. The results showed that students were at a medium level of environmental awareness, both in theory and practice, as they had a good understanding in theory but were not actively involved in environmental activities. In terms of positive effects, students demonstrated their ability to use smartphones as tools to raise awareness and promote sustainable practices, including using less paper and taking part in digital environmental efforts. But the problems were that there was more e-waste because phones were being replaced so often and energy consumption was unnecessary. The study revealed a moderate positive correlation between the use of smartphones and the adoption of sustainable practices, indicating the role of smartphones in environmental activities. The study recommends some solutions, including creating an environmental awareness app, holding digital competitions, etc. It suggests raising awareness among students regarding recycling and electronic waste and promoting the use of smartphones in a sustainable manner for a positive impact on the environment.

Keywords: smartphones; environmental sustainability; environmental awareness; sustainable practices; university students

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1. Introduction

Technology is a crucial aspect of everyday life, making communication easier and information more accessible. This field is rapidly evolving, and technological advances are playing a major role in sectors such as education, health, and environmental sustainability, which are vital to achieving a more efficient and sustainable future [1].

One of the most visible technologies today is the cellphone, which has become a near-essential part of everyday life. Cellphones offer many advantages, including increased access

to information, support for education, and reduced paper use through digital applications. However, smartphone production consumes substantial natural resources, and improper disposal contributes to environmentally harmful electronic waste [2].

Smartphones can positively contribute to environmental sustainability by raising environmental awareness, reducing resource consumption, and encouraging sustainable behavior, for example through applications that help users monitor their carbon footprint or access recycling information [3]. Current technological advances also reduce the need for physical mobility through distance learning and virtual meetings, which can help lower transport-related emissions and conserve resources [4].

Among university students, high levels of smartphone use create opportunities to support sustainable practices when appropriate tools, awareness, and institutional support are available. Because students rely heavily on technology for learning and communication, smartphones can support sustainability through smart applications, digital environmental campaigns, and reduced unnecessary consumption of natural resources [5].

This research aims to study the impact of smartphones on enhancing environmental sustainability among AAU students, by analyzing their environmental awareness and digital behaviors, and determining the extent to which they benefit from technology in achieving environmentally friendly practices, which contributes to providing recommendations to enhance the role of smartphones in achieving sustainability within the university community.

Smartphones have become an integral part of daily life, with an estimated 18.22 billion mobile devices in use globally by 2025, more than double the global population [6]. In the UAE, smartphone penetration has likewise become very high, reinforcing the importance of understanding the environmental implications of device use [2].

Despite the many benefits these devices offer, smartphones also have substantial environmental impacts associated with resource-intensive production, frequent replacement, energy use, and electronic waste. Research among university students has linked frequent charging and device replacement with greater electricity use and waste electrical and electronic equipment generation [7], while UAE evidence shows that environmental awareness and convenient recycling systems are important for responsible end-of-life smartphone disposal [8,9]. Belkhir and Elmeligi [10] estimated that the relative contribution of smartphones to the ICT greenhouse-gas emissions footprint increased from 4% in 2010 to 11% in 2020. In absolute terms, their model estimated that smartphone-related greenhouse-gas emissions increased from approximately 17 MtCO2-e in 2010 to 125 MtCO2-e in 2020. These estimates should be interpreted cautiously because they depend on modelling assumptions about ICT life-cycle emissions, device production, and replacement cycles.

In the UAE, the government has promoted environmental sustainability through multiple initiatives, including digital tools designed to raise public awareness of carbon emissions [11]. Nevertheless, there remains an urgent need to understand how intensive smartphone use affects the environment, especially among university students, who represent a major group of technology users [12].

Based on the preceding discussion, the study addresses the following research questions:

1. What is the level of environmental sustainability awareness among Al Ain University students?
2. What are students' perceived positive uses of smartphones in relation to environmental sustainability?
3. What are students' perceived negative environmental consequences of smartphone use?
4. What is the association between students' smartphone use for sustainability-related purposes and their self-reported adoption of sustainable environmental practices?
5. What proposals do students support for using smartphones to promote sustainable environmental practices?

The theoretical significance of this study stems from its contribution to enriching the scientific literature on the relationship between smartphones and environmental sustainability, as it sheds light on the role that technology can play in achieving environmental goals. The study also contributes to bridging the knowledge gap around university youth's awareness of the concept of environmental sustainability and the impact of smartphones on it, which may help researchers and those interested in developing new theoretical models on the use of technology to promote sustainable environmental behaviors.

Moreover, the findings of this study can be beneficial to the decision makers of the university and environmental institutions in making recommendations to improve the use of smartphones in promoting environmental awareness and sustainable behaviors among students in practice. The results can also be used to create awareness programs and smart applications that will support environmental sustainability, such as reducing energy use, promoting recycling and reducing the carbon footprint. Furthermore, the results of this study can provide students with an understanding of how their digital activities can affect the environment and thus become responsible when conducting digital activities.

2. The Theoretical Premise of the Study

This study is based on two main theoretical perspectives that illustrate the relationship between smartphones and environmental sustainability among AAU students:

First, Everett Rogers' Diffusion of Innovations Theory explains how new technologies are adopted and used in society [13]. According to this theory, individuals progress through stages of awareness, persuasion, decision, implementation, and confirmation when adopting an innovation [13]. In the present study, the theory helps explain how students may adopt smartphone-based practices that support environmental sustainability, such as using environmental applications, paperless learning tools, and digital sustainability campaigns. From this perspective, students can first become aware of sustainability-related smartphone functions, evaluate their usefulness, and eventually integrate them into repeated sustainable behavior.

Second, the Theory of Planned Behavior developed by Icek Ajzen proposes that behavior is influenced by attitudes, subjective norms, and perceived behavioral control [14]. In this study, students' awareness of environmental sustainability, the influence of their social environment, and their perceived ability to make a difference through smartphone-supported actions may all shape environmental decisions and behavior. The theory also helps explain why awareness does not always translate into lasting action: positive attitudes may be insufficient when social norms, institutional support, perceived control, or opportunities for sustainability-related participation are weak.

Diffusion of Innovations Theory helps explain the extent to which students accept the use of smartphones to promote environmental sustainability, and who is most responsive to these digital environmental innovations. The Theory of Planned Behavior provides a framework for understanding the factors that influence students' decisions to adopt sustainable environmental practices via smartphones, helping to develop strategies to promote this behavior. By combining these two theories, it is possible to understand how the use of smartphones contributes to the dissemination of a culture of environmental sustainability among university students, and what factors may hinder or support this trend.

3. Literature Review

Climate change, environmental degradation, depletion of natural resources, and rapid technological development have made environmental sustainability one of the most pressing global issues in recent decades. Universities face increasing pressure to contribute to sustainable development by fostering environmental awareness, responsible behavior, and green

innovation among students. In this context, digital technologies, smartphones, artificial intelligence, and smart educational systems can support sustainability learning by expanding access to environmental information and interactive educational experiences [5,15,16]. At the organizational level, related research also shows that digitally enabled innovation, green capacity, green energy, financial inclusion, and fintech can contribute to sustainability-oriented outcomes [17,18]. At the same time, technology dependence can increase electronic waste, energy consumption, and unsustainable device-use patterns [7,19,20]. This dual nature of technology raises an important question: whether technological integration genuinely fosters sustainable behavior or merely shifts environmental pressures into new digital forms.

Sustainability and digital transformation are key national priorities in the United Arab Emirates (UAE), including the national objective of achieving Net Zero by 2050. This has encouraged the adoption of new technologies in educational systems to facilitate sustainable education and strengthen students' environmental awareness. The UAE higher-education sector has increasingly integrated digital transformation with environmental and technological goals [5,16,21]. However, despite rapid technological progress, questions remain about the extent to which students' technology use translates into sustainable environmental behavior [22].

Evidence from the region and internationally demonstrates the educational value of sustainability-focused learning, while also showing that knowledge alone does not consistently lead to sustainable behavior. In a cross-sectional survey of 823 students at United Arab Emirates University, Al-Naqbi and Alshannag [5] reported high levels of sustainability knowledge and positive attitudes but only moderate levels of positive environmental behavior. UNESCO [15] similarly notes that digital technology can expand access to information and interactive learning, but educational purpose, evidence, governance, and attention to longer-term social and environmental costs remain essential.

A persistent awareness-behavior gap has also been reported in the region. Al-Naqbi and Alshannag [5] found that UAE university students showed relatively high sustainability knowledge and attitudes while their behaviors were more moderate. This suggests that information and positive attitudes need to be complemented by institutional opportunities, perceived behavioral control, and practical sustainability initiatives. Roth and Sezgin [20] likewise emphasize that environmentally sustainable ICT depends on user behavior, device replacement patterns, energy consumption, resource utilization, and electronic-waste management.

The effect of mobile technologies on environmental behavior has also been examined directly. Mâță et al. [23] found that university students generally view mobile technologies as useful for learning and communication, while Islam and Khan [22] reported that digital learning environments can strengthen sustainability information exposure and ecological thinking. Qiang et al. [7] showed, however, that frequent charging and device replacement among university students can create energy-use and electronic-waste concerns. UAE research similarly indicates that environmental awareness can support responsible smartphone recycling, although personal and infrastructural barriers may inhibit action [8,9]. This dual effect is consistent with broader sustainability research on both the educational benefits and environmental costs of digitalization [19,20].

In recent years, a growing body of research has examined artificial intelligence (AI) and its application to sustainable education. AI-enabled educational systems can optimize learning processes, reduce paper use, and offer tailored sustainability learning experiences. Al-Emran et al. [21] show how generative AI can be linked with social sustainability in higher-education contexts, while Dwivedi [24] discusses AI-related opportunities and challenges for sustainable higher education. More recent evidence indicates that AI-related technological and environmental drivers can strengthen sustainability-oriented capabilities in higher

education [16] and that AI-enabled digital strategies can support broader business sustainability through innovation mechanisms [25]. These benefits must nevertheless be balanced against the computing power and energy-intensive infrastructure required by AI systems. UNESCO [15] therefore cautions that rapid digital growth without appropriate environmental governance can aggravate sustainability challenges rather than resolve them.

Sustainability in computing and digital education is therefore an important research area. Peters et al. [19] argue that sustainability concepts remain insufficiently integrated into computing curricula and recommend teaching sustainable software development, green computing, carbon reduction, and electronic-waste management. Roth and Sezgin [20] further show that digital behavior is shaped by technology-consumption culture, which may contribute to unsustainable patterns. Universities consequently need to promote green ICT practices and environmentally responsible digital behavior through institutional policies, curriculum design, and awareness initiatives.

Institutional support is an important prerequisite for moving from environmental awareness to sustainable action. Kurniawan [26] argues that technological sustainability initiatives are more effective when environmental sustainability is integrated across campus operations, academic programs, and institutional policies rather than addressed in isolation. Dwivedi [24] similarly highlights the importance of institutional reinforcement mechanisms such as sustainability-oriented teaching, environmental campaigns, and green-campus projects. These findings align with the view that technology-related awareness must be coupled with practical environmental action [5]. Related organizational research also shows that green human-resource practices, employees' green behavior, renewable-energy orientation, and green knowledge can help translate sustainability intentions into stronger environmental and organizational outcomes [27,28].

Research on digital technology, sustainable education, and student action has expanded substantially. UAE university students have shown relatively high levels of sustainability knowledge and attitudes but more moderate sustainable behavior, indicating an awareness-action gap [5]. UNESCO [15] notes that digitalization can broaden access to sustainability information and interactive learning, while Roth and Sezgin [20] emphasize the environmental impacts associated with device ecosystems, energy consumption, replacement patterns, and electronic waste. Collectively, these findings indicate that smartphones can promote environmental learning while simultaneously creating environmental pressures that require responsible management and institutional support.

Recent studies continue to question how effectively digital technologies foster sustainable behavior. Peters et al. [19] note that educational institutions may emphasize technological development without giving sufficient attention to the environmental impacts of high digital consumption and unsustainable technological practices. UNESCO [15] likewise recognizes that digital tools can broaden access to sustainability information while also contributing to electronic waste and environmental burdens when growth is poorly governed. Islam and Khan [22] report that digital learning environments can strengthen sustainability motivation and awareness, while Al-Emran et al. [21] illustrate the growing role of AI in higher-education sustainability. Roth and Sezgin [20] further emphasize that students' digital behavior is shaped by technology culture and consumption patterns, which can either support or hinder sustainable environmental practices.

Other recent studies provide further support for the present research questions. Torroba Diaz et al. [29] found that environmental knowledge and attitudes positively influence university students' environmental behavior. Kronrod et al. [30] showed that combining encouraging and discouraging messages can facilitate engagement with new pro-environmental practices. Benzehaf et al. [31] documented a gap between environmental awareness, attitudes, and action among university students, while Chen and Erfanian [32]

identified attitudes, subjective norms, and perceived behavioral control as important predictors of campus pro-environmental behavior. These findings provide a contemporary basis for interpreting the present study.

While there are numerous studies that have investigated the relationship between modern technology and environmental sustainability, most studies have been aimed at environmental awareness and did not consider the direct association between smartphones and the actual adoption of sustainable environmental behavior. Furthermore, previous research focused mainly on the positive impacts of technology on EE, or the negative environmental impacts of technology, but did not consider both aspects at the same time. Thus, it is important to emphasize that the current study has a specific focus on the direct connection between student use of smartphones and the adoption of sustainable environmental practices in learning contexts, as this has not been analyzed in previous studies. The study also aims to offer a balanced view, taking into account the positive and negative impacts of the use of smartphones on environmental sustainability and proposing solutions and recommendations that can be implemented to reinforce the positive role of smartphones in fostering sustainable environmental behavior in the university environment.

4. Materials and Methods

The study design used was a descriptive–analytical research design to explore the relationship between the use of a smartphone and environmental sustainability among the students of Al Ain University. It was determined that the descriptive–analytical method is suitable for collecting, organizing and analyzing data systematically in order to be able to identify patterns, relationships and interpretations about the phenomenon researched.

The study was carried out in a specified spatial, temporal and human context. The research was conducted in a specific geographical area, namely students studying at Al Ain University in the United Arab Emirates (UAE), with the aim of examining the effect of the use of smartphones on the promotion of environmental sustainability in this educational setting. In terms of time, the study was conducted in the second semester of 2024/2025. In terms of aspects of the human boundaries, the study aimed to explore the impact of smartphone on the students' environmental awareness and behaviors, among students from different academic disciplines who use smartphones frequently.

The study population was all the students of Al Ain University in Abu Dhabi and Al Ain campuses. As per the University records of the academic year 2024, there are 865 students in total, spread across six colleges of the University, namely Engineering, Pharmacy, Law, Education, Humanities and Social Sciences, Business, and Communication and Media. A voluntary non-probability sample of 90 students participated, consisting of 50 male students (55.6%) and 40 female students (44.4%). The sample size was not very large, but this was deemed to be adequate for an exploratory cross-sectional survey. The population of the study comprised 865 students from 6 colleges of AAU. At a 95% confidence level, with the assumption of maximum variability and with a margin of error of approximately 10%, the minimum sample size was 87 students. Thus, the final sample of 90 students was sufficient for preliminary descriptive and correlational analysis. The results must be treated with some reservation, however, and should not be extrapolated to other AAU samples without additional testing with larger and multi-university samples. The retained study records do not contain a complete sampling frame, a random-number selection procedure, or the number of students invited to participate. Consequently, a response rate cannot be calculated, and the sample should not be described as a simple random sample.

The data used in this study were obtained from a structured questionnaire that was prepared specifically for this study. The most important research tool was the questionnaire, which aimed to assess students' environmental sustainability awareness, the positive and

negative impacts of smartphones on environmental practices and suggestions to enhance the role of smartphone in the promotion of sustainable environmental behavior. Furthermore, a section of the questionnaire was dedicated to participant information such as background and participant characteristics that would allow analysis based on these factors. The available participant characteristics are gender, reported above. Age, academic discipline, year of study, and campus-level distributions were not available in the retained analysis file and therefore could not be reported or used for subgroup analysis.

The questionnaire was structured with a 5-point Likert scale with four factors. The first dimension was students' awareness of concepts of environmental sustainability which comprised questions related to carbon footprint and recycling, and UAE's environmental efforts. The second dimension involved the positive themes of importance of smartphones to environmental sustainability, such as environmental applications, digital learning, and involvement in environmental programs, in addition to the reduction of paper use. The third dimension emphasized the destructive consequences of utilizing a cell phone, for example, electronic waste and excessive energy use. The fourth dimension delved into proposals and suggestions to consolidate the capabilities of smartphones to disseminate sustainable environmental practices like creating awareness apps and digital environmental campaigns. Mean scores were interpreted using three categories: low = 1.00–2.33, medium = 2.34–3.67, and high = 3.68–5.00. The Likert scale items were ordinal categorical, but in order to be descriptive, the mean score was used since each construct was measured by several items, and the scores showed acceptable internal consistency.

The validity of the research instrument was determined by having the questionnaire reviewed by a panel of the university professors and experts in the fields of environment and education. The questionnaire was judged by the experts on its clarity, relevance and appropriateness to the study objectives. Following their feedback and recommendations, a few changes were made in the wording, clarity and overall appropriateness of the instrument.

For the questionnaire, the level of reliability was tested for each dimension and for the entire questionnaire using the Cronbach's alpha coefficient. Cronbach's alpha is a widely used measure of internal consistency of items in a questionnaire and is commonly used to assess the degree of similarity between the items of the questionnaire. Reliability coefficients > 0.70 were regarded as acceptable and the values >0.80 as having a high degree of internal consistency and reliability. The reliability results are presented in Table 1.

Table 1. Values of Cronbach alpha coefficient for the stability of the study instrument.

Axis	Number of Items	Cronbach's Alpha Coefficient (α)	Reliability Level
Level of awareness of Al Ain University students about environmental sustainability	5	0.81	High
Positive effects of smartphones in promoting environmental sustainability	5	0.85	High
Negative impacts of smartphones on environmental sustainability	5	0.78	Acceptable
Proposals to enhance the role of smartphones in disseminating sustainable environmental practices	5	0.83	High
Overall score of the study instrument	**20**	**0.82**	**High**

Table 1 shows that all the axes of the questionnaire have high Cronbach's alpha values, ranging between 0.78 and 0.85, which indicates that the study tool has a high degree of stability and can be relied upon to collect data related to environmental sustainability and the use of smartphones among Al Ain University students.

5. Results

This section introduces and interprets the results of the study on the role of smartphones in improving environmental sustainability among the students of Al Ain University. The results were analyzed based on the responses collected from the study sample in order to evaluate students' level of environmental awareness, their use of smartphone technologies in supporting sustainable practices, and the challenges associated with environmental sustainability. The section also emphasizes the connection between technological use and sustainable behavior, and the interpretation of the statistical results in relation to the study purposes and sustainability literature. Cronbach's alpha was used to determine the reliability of the questionnaires, both for each dimension and for the whole questionnaire. The overall reliability value was acceptable, which means that there was internal consistency among the questionnaire items. Furthermore, the correlation analysis was presented with the sample size, degrees of freedom, level of significance and the confidence interval to enhance the statistical clarity. While these analyses offer initial validation of the results, larger samples, confirmatory factor analysis, and longitudinal or experimental designs would all provide more.

Table 2 shows that the overall level of awareness about environmental sustainability among the students of Al Ain University is moderate (3.34) with a standard deviation of (0.88). The highest mean (3.85) with a standard deviation of (0.74) was for the students' knowledge of the concept of "environmental sustainability" and its significance in conserving natural resources. This finding suggests that students' theoretical understanding of sustainability concepts and environmental protection is relatively good. Likewise, the mean score for awareness of the UAE Environmental Sustainability Initiative and Vision 2050 was medium (3.62) indicating that students are aware of national environmental initiatives and policies. However, the results indicated moderate awareness of the concept of the carbon footprint and the use of environmentally friendly products, with arithmetic mean scores of (3.45) and (3.12), respectively, indicating that the students could express their understanding of the concept, but in practice, the use of environmentally friendly behavior is limited. The last item was participation in environmental activities and initiatives within the university/community, with a medium mean of (2.68) and a standard deviation of (1.05); this shows that students were not engaged in any practical activities or initiatives relating to the environment, although they were aware of it theoretically. The results taken as a whole indicate that students have a consciousness of the environment, but more efforts at the institutional level are needed to make this awareness a reality through sustainable practices and environmental participation. The findings further indicate an environmental awareness–practice disconnect. Pupils' awareness of sustainability issues was present but their practical involvement in environmental activities was less. These differences could be attributed to low perceived behavioral control and lack of social encouragement, institutional support, and opportunities for students to engage in sustainability activities. Awareness, therefore, is not an adequate driver of sustainable behavior without the support of systems within the university, environmental campaigns, recycling facilities, participation platforms and incentives for student participation.

Table 2. Values of arithmetic averages and standard deviations of the responses of the study sample members to the paragraphs related to the level of awareness of Al Ain University students in environmental sustainability.

Rank	No.	Paragraph	Arithmetic Mean	Standard Deviation	Grade
1	1	I am familiar with the concept of environmental sustainability and its importance for the conservation of natural resources.	3.85	0.74	High
2	3	I have knowledge of the UAE Environmental Sustainability Initiative and Vision 2050.	3.62	0.81	Medium
3	2	I can define the term "carbon footprint" and its impact on the environment.	3.45	0.89	Medium
4	4	I use products that are recyclable or made from environmentally friendly materials.	3.12	0.92	Medium
5	5	I participate in environmental activities or initiatives within the university or in the community.	2.68	1.05	Medium
Overall Mean			**3.34**	**0.88**	**Medium**

Table 2 shows that the general arithmetic average of the awareness level of Al Ain University students regarding environmental sustainability was (3.34) with a medium degree, which reflects a reasonable level of awareness but needs to be enhanced through awareness and actual environmental practices. The highest arithmetic average (3.85) was for the first paragraph: "I am familiar with the concept of environmental sustainability and its importance for the preservation of natural resources." This suggests that there is a high level of theoretical understanding among most students of sustainability and its significance. The paragraph on knowledge of the UAE Sustainability Initiative and Vision 2050 was given an average score of (3.62), which was medium, reflecting a comparatively strong level of awareness within the medium category of these national initiatives. The parameters "carbon footprint" (3.45) and the use of eco-friendly products (3.12) were rated as average, indicating that there is knowledge, but its application should be further improved. The lowest arithmetic average (2.68), which remained within the medium category was for the paragraph on participation in environmental programs, showing that there is not a strong demand for environmental activities even though there is theoretical awareness.

To answer the second question of the study, the arithmetic averages and standard deviations of the responses of the study sample were extracted for the paragraphs of the questionnaire related to the positive effects of smartphones in enhancing environmental sustainability among Al Ain University students, and Table 3 illustrates this.

Table 3 shows that the general arithmetic average of the positive effects of smartphones in enhancing environmental sustainability among Al Ain University students was (3.45) with a moderate degree, which indicates that students are somewhat aware of the role of smartphones in promoting environmental sustainability, but the level of actual utilization varies between paragraphs. The highest arithmetic average (3.92) was for the first

paragraph: "I use my smartphone to access environmental information and awareness of sustainability." This shows that students rely heavily on smartphones as their main source of environmental knowledge. The paragraph on reducing paper consumption through smart applications received an average of (3.75), which reflects a good environmental awareness among students regarding reducing the consumption of paper resources. The use of smart transportation applications to reduce carbon emissions (3.48) and to rationalize energy and water consumption through applications (3.21) received average scores, indicating that some students apply these environmental practices, but not extensively. The lowest arithmetic average (2.89) was for the paragraph related to following up and participating in environmental initiatives via smartphone, which indicates the lowest, but still medium, level of interaction with actual environmental activities despite the availability of digital means that facilitate this.

Table 3. Values of arithmetic averages and standard deviations of the responses of the study sample members to the paragraphs related to the positive effects of smartphones in enhancing environmental sustainability among Al Ain University students.

Rank	No.	Paragraph	Arithmetic Mean	Standard Deviation	Grade
1	1	I use my smartphone to access environmental information and sustainability awareness.	3.92	0.70	High
2	2	I rely on smart apps to reduce paper consumption in my daily studies.	3.75	0.78	High
3	3	I use ride-hailing apps and smart transportation to reduce carbon emissions.	3.48	0.85	Medium
4	5	I use resource management apps to rationalize energy and water consumption in my daily life.	3.21	0.90	Medium
5	4	I follow and participate in environmental initiatives through my smartphone.	2.89	1.02	Medium
Overall Mean			**3.45**	**0.85**	**Medium**

To answer the third question of the study, the arithmetic averages and standard deviations of the responses of the study sample were extracted for the paragraphs of the questionnaire related to the negative effects of smartphones on environmental sustainability among Al Ain University students, and Table 4 illustrates this.

Table 4 indicates that the general arithmetic mean of the negative impacts of smartphones on environmental sustainability among Al Ain University students was (3.49) at an average level, suggesting that the students have a relative awareness of these impacts but there are still some negative practices that are prevalent. Frequent smartphone replacement was the greatest arithmetic average (3.85) which means that students often change their smartphones to new ones, generating e-waste. The paragraph on leaving the phone connected to the charger for long periods received an average score of (3.72), which indicates unnecessary power consumption among students. Lack of interest in recycling electronic devices received an average score of (3.54), reflecting the need to promote a culture of recycling and proper disposal of electronic devices. The average use of the phone for long periods per day (3.29) and the average purchase

of unnecessary accessories and devices (3.05) indicate that these negative habits exist but are less prevalent compared to other habits.

Table 4. Values of arithmetic mean and standard deviations of the responses of the study sample to the paragraphs related to the negative effects of smartphones on environmental sustainability among Al Ain University students.

Rank	No.	Paragraph	Arithmetic Mean	Standard Deviation	Grade
1	1	I replace my smartphone frequently, which contributes to an increase in e-waste.	3.85	0.74	High
2	2	I leave my phone plugged into the charger for long periods without need, which consumes unnecessary power.	3.72	0.81	High
3	3	I do not care about recycling old electronics or disposing of them in environmentally friendly ways.	3.54	0.88	Medium
4	4	I use my phone for long periods every day, which increases electricity consumption and emissions from energy production.	3.29	0.91	Medium
5	5	I buy unnecessary accessories and electronics, which contributes to excessive consumption of resources.	3.05	1.03	Medium
Overall Mean			**3.49**	**0.87**	**Medium**

To answer the fourth research question, the smartphone-use and sustainable-practices scores were analyzed using Pearson's correlation coefficient to determine the strength and direction of their association. Table 5 presents the results of this correlation analysis.

Table 5. Correlation coefficient between students' use of smartphones and their adoption of sustainable environmental practices.

Variables	N	Mean of Smartphone-Use Score	Mean of Sustainable-Practices Score	r	df	*p*-Value	95% CI
Smartphone use and sustainable environmental practices	90	3.58	3.35	0.62	88	$p < 0.001$	[0.47, 0.73]

The results indicate a positive correlation between the use of smartphones and students' adoption of sustainable environmental practices, with the Pearson correlation coefficient being (0.62), which reflects a positive and medium strength correlation between the two variables. Statistical significance ($p < 0.001$) also confirms that the relationship is significant, which means that increasing the use of smartphones in environmental activities may contribute to enhancing students' adoption of sustainable environmental practices.

To answer the fifth question, the arithmetic averages and standard deviations of the responses of the study sample were extracted for the questionnaire items related to the proposals to enhance the role of smartphones in spreading and promoting sustainable environmental practices among AAU students, and Table 6 illustrates this.

Table 6. Values of arithmetic averages and standard deviations of the responses of the study sample to the paragraphs related to proposals to enhance the role of smartphones in spreading and promoting sustainable environmental practices among Al Ain University students.

Rank	No.	Paragraph	Arithmetic Mean	Standard Deviation	Grade
1	3	Organizing digital environmental competitions via smartphones will encourage students to practice sustainably.	4.21	0.76	High
2	1	Developing university awareness applications to enhance awareness of environmental sustainability among students.	4.15	0.82	High
3	2	Integrating environmental sustainability into digital curricula will motivate students to adopt environmentally friendly practices.	4.10	0.88	High
4	4	Providing interactive guidance through smartphones on recycling and resource conservation.	3.95	0.91	High
5	5	Promoting the use of smart transportation applications among students will contribute to reducing carbon emissions.	3.80	0.97	High
Overall Mean			**4.04**	**0.87**	**High**

The overall arithmetic average (4.04) indicates that students have a high level of acceptance of proposals aimed at enhancing the role of smartphones in supporting sustainable environmental practices. The highest response was to the section "Organizing digital environmental competitions via smartphones" with an arithmetic average of (4.21), indicating that students believe that digital competitiveness can be a powerful catalyst for promoting positive environmental behavior. The harmful effects of smartphone usage need to be considered, too. The disposal of the devices is a serious issue because of e-waste, and long charging times and unnecessary usage during the day add to the energy consumption. Furthermore, there are potential environmental consequences of smartphone use due to a lack of knowledge when it comes to recycling and environmentally responsible disposal. This study revealed that the application of smartphones can facilitate sustainability awareness but can also pose sustainability issues when used in an irresponsible way or when discarded.

The second place was achieved by the special paragraph "Developing university awareness applications to enhance environmental awareness" with an average of (4.15), indicating

the need to increase the use of special applications in the digital area to encourage students to be more environmentally conscious. The averages of the paragraphs "Providing interactive guidance on recycling" and "Promoting the use of intelligent transportation applications" were (3.95) and (3.80), respectively, meaning that these proposals also fell within the high category, although their means were lower than those of the leading proposals.

6. Discussion

6.1. Research Question 1: Environmental Sustainability Awareness

The results of the study showed that the level of environmental sustainability awareness among Al Ain University students was moderate, which means that students have an acceptable theoretical knowledge of the concepts of sustainability, the importance of preserving the environment and conserving resources. Students had more awareness of the importance of environmental sustainability and the UAE national initiatives in this area, including UAE Vision 2050 and governmental policies geared towards sustainability. These findings are indicative of the growing presence of environmental sustainability discourse in the UAE, both in educational institutions as well as in the wider social context. The results also showed that while the theoretical awareness was relatively satisfactory, the students' participation in the environment-related activities and actions was also lower, which indicated that the students' environmental awareness was more knowledge-oriented than behavior-oriented. This discovery suggests that there is still a disconnect between environmental awareness and environmental action among students at university.

The findings are consistent with other studies, which have found that university students show moderate to high levels of environmental awareness, but are less likely to engage in sustainable environmental actions [5,29,31]. Despite the positive results that environmental education (EE) and digital communication have brought about in the field of sustainability awareness, it remains unclear whether sustainable behavior can be achieved, or even sustained, without the presence of enabling subjective norms, perceived behavioral control, institutional opportunities, and mechanisms for meaningful participation [32]. It is, therefore, essential for universities to link the knowledge of sustainability with easy-to-access environmental projects, recycling systems, incentives, and curriculum-based activities.

The results of this study can be understood by reference to Rogers' Diffusion of Innovations Theory and Ajzen's Theory of Planned Behavior. According to Rogers' theory, students' awareness and persuasion regarding sustainability and the learning about environment using smartphones show good progress; however, many students are not yet fully transitioned to the implementation and confirmation stage, where sustainable environmental behavior is being incorporated into everyday life. Similarly, the Theory of Planned Behavior indicates that positive attitudes do not necessarily translate into environmental behaviors, but that subjective norms, institutional support, perceived behavioral control, and environmental motivation are other factors that influence students' environmental behaviors [14,32]. So, for people to behave in an environmentally sustainable manner, it is not enough to have environmental awareness alone since it has to be accompanied by a supportive environment at the university, practical environmental actions, and organizational support for environmental participation and reinforcement.

6.2. Research Question 2: Positive Smartphone Uses for Sustainability

The findings also showed that utilizing smartphones is contributing positively to the enhancement of the awareness of environmental sustainability among students at Al Ain University. Students often rely on their smartphones as a tool to access environmental information, sustainability-related applications, environmental campaigns and digital sustainability information. Similarly, smartphones were positively correlated with the reduction of paper

consumption through the use of digital applications, smart transportation and energy and water resource management practices. The results show that smartphones have become significant tools in education and behavioral change that can be used to help achieve environmental learning and sustainability-oriented actions among university students.

The results of the current study align with previous research that highlighted the role of smartphones and other digital technologies in promoting environmental learning and sustainability awareness among young and university students [5,22,23]. In recent sustainability and higher education research, the conclusions were similar, with most studies stating that digital technologies can help positively affect environmental engagement, by making environmental information more accessible, providing reinforcement and support to sustainability communication, and facilitating interactive learning experiences about the environment [29–31]. More recent studies also indicate that the role of smartphones for fostering sustainable behavior is positive when they are connected to institutional sustainability frameworks and environmental education strategies as these approaches will enable students to have access to digital platforms for raising awareness of sustainability, participating in sustainability, and sustaining their decisions [20,32]. Further, there is a growing call by sustainability scholars for a more sustainable use of smartphones and smart technologies to help students be more aware of their environment: smart technologies can provide students with immediate access to sustainability information, environmental monitoring applications, and environmentally friendly lifestyle alternatives [30,31].

In spite of these positive consequences, the results showed that the use of smartphones for environmental action and participation in sustainability was relatively low, suggesting that students' use of their smartphones is more geared toward environmental awareness and information than toward active environmental action and participation in sustainability. This result is consistent with the "awareness-action gap" that has been described in much of the recent sustainability literature, in which one's awareness of sustainability does not necessarily lead to environmental action that is sustainable [31,32]. Previous research also found that while students are increasingly aware of the significance of environmental sustainability, there is a lack of individual commitment to sustainable practices and opportunities for students to be directly engaged in environmental activities, which is partly attributed to low institutional support, environmental motivation and opportunities [29,31]. Therefore, environmental awareness does not necessarily lead to sustainable behavior without incorporating sustainability-related initiatives, real participation opportunities and an institutional sustainability culture into the students' learning process.

6.3. Research Question 3: Negative Environmental Consequences of Smartphone Use

The results also showed that university students experience negative environmental impacts from their smartphones as well. This study indicates that while smartphones provide a positive influence on environmental awareness, there are also significant environmental sustainability issues regarding energy consumption, technological dependence and electronic waste.

This result is well aligned with previous studies that have raised the conflicting nature of smartphones in sustainability debates [5,8,20]. Previous research highlighted both the environmental awareness role and environmental degradation role of smartphones due to the overuse of technology, energy, and the production of e-waste [5,8]. Similarly, the sustainability paradoxes of digital technologies were discussed in recent research, as technology development on one hand can enhance environmental communication but on the other hand can lead to environmental pressure due to technological production and consumption systems [20,32]. Today's research also indicates that consumer-oriented technological culture and constant smartphone upgrading play a major role in the unsustainable

consumption of smartphones among university students, such as unnecessary smartphone replacements and inadequate electronic waste recycling [20,31]. Thus, to encourage the sustainable use of technology, universities need to take into account how to make people more aware of sustainability issues in digital culture by promoting electronic recycling, energy savings and environmentally friendly smartphone use.

6.4. Research Question 4: Smartphone Use and Sustainable Practices

The results also revealed a positive and statistically significant relationship between the students' utilization of smartphones and the use of sustainable environmental practices. Regarding the students' environmentally responsible behavior, a moderate positive relationship was suggested by the Pearson correlation coefficient, which showed that higher use of smartphones for sustainability-related activities had a positive impact on the students' environmentally responsible behavior. This discovery supports the use of smartphones as a powerful sustainability education and behavior change tool that can be leveraged through digital environmental awareness, sustainability applications, and environmentally oriented technology engagement.

The current results are consistent with previous studies highlighting the positive influence of smartphones and digital innovations on environmental awareness and sustainable environmental behavior among students [5,7,22,23,30,32]. Recent behavioral and sustainability studies likewise show that environmental knowledge, digital involvement, and sustainability-oriented teaching and learning environments can positively influence pro-ecological behavior and environmentally responsible decision-making [31,32]. The combination of sustainability education and behavioral theory further suggests that smartphones may strengthen perceived behavioral control and environmental intentions by providing practical tools such as smart transportation systems, resource-conservation applications, and recycling guidance [20,32]. Overall, these findings provide further support for Rogers' Diffusion of Innovations Theory: students who successfully adopt smartphone-based sustainability innovations may be more likely to integrate sustainable environmental practices into daily life.

6.5. Research Question 5: Student-Supported Sustainability Proposals

Lastly, the results indicated high acceptance among the students of the proposed interventions to improve the role of smartphones in promoting sustainable environmental practices. Digital environmental competitions, university sustainability applications, sustainability-integrated digital teaching and curricula and recycling guidance systems using smartphones received especially high support from students. These findings suggest that students believe that the use of smartphones and smart technologies is motivational and educational devices and can enhance student engagement in sustainability and environmental involvement in university settings.

The results of the current study are well supported by recent sustainability-education research on the positive effects of interactive digital technologies, sustainability-oriented educational applications, and smartphone-based environmental projects on students' environmental attitudes, sustainability awareness, and environmentally responsible behavior [29,30,32]. Recent research also recommends greater integration of sustainability education into digital university curricula and the use of mobile technologies as practical sustainability tools [31,32]. Furthermore, interactive approaches such as digital environmental competitions, smart sustainability applications, and technology-supported campaigns can strengthen environmental motivation and participation by making sustainability engagement more accessible and digitally communicative [20,30]. The present findings therefore support the growing literature suggesting that smartphones can serve as sustainability-

supportive technologies when embedded within institutional sustainability frameworks, practical engagement strategies, and behavior-oriented education.

7. Conclusions

The present study analyzed the role of smartphones in promoting an environmentally friendly attitude among the students of Al Ain University in the context of technological transformation and sustainable development in the United Arab Emirates. The results showed that the smartphone is becoming a significant instrument for education and behavior change that can facilitate awareness of the environment and environmental education, green learning and environmentally friendly behavior among university students. Simultaneously, the research revealed that smartphones can also raise environmental issues regarding the overuse of digital devices, e-waste production, and wasted energy. As such, smartphones are both a challenge and an opportunity in the modern discourse on environmental sustainability.

The results showed that students' theoretical understanding of environmental sustainability and the importance of preserving natural resources is relatively good. The students also exhibited their knowledge about the national initiatives for sustainability, including UAE Vision 2050 and other UAE governmental sustainability initiatives, which indicates the growing importance of sustainability in the UAE's educational and developmental landscape. Nevertheless, although they were aware of these things, their involvement in environmental projects and activities focused on sustainability was not very high. It is also observed that there is still a gap between the environmental awareness and sustainable behaviors among the university students.

Additionally, the study found that smartphones have a positive impact on environmental sustainability through the provision of information regarding the environment, environmentally related applications, digital environmental awareness campaigns and environmentally oriented educational content. Students are increasingly using smartphones for paperless learning, smart transportation applications and energy and water resource management practices. The results of this research show that the use of smartphones, in the context of educational settings and institutional sustainability systems, can stimulate sustainability-related behavior.

However, the study also highlighted some adverse environmental impacts of the use of cell phones. Smartphone replacement, extended charging habits, poor e-waste recycling habits and unsustainable digital consumption were prominent environmental issues identified among students. The results indicate that smartphones can be used in an environmentally friendly way, but they also increase environmental problems with e-waste production and unnecessary usage of valuable resources. Hence, sustainable technological behavior has become a key priority in ensuring that digital transformation can be a positive force for environmental sustainability and not a source of environmental pressure.

The most important finding of the study was that there was a positive and statistically significant relationship between the use of smartphones and students' implementation of sustainable environmental practices. The results mirror previous studies indicating that the use of digital technologies can positively shape environmentally responsible behavior when the smartphone is used for educational purposes that are related to environmental issues, including environmental awareness, sustainability applications, recycling advice, and environmentally friendly transportation. The results thus support the view that digital technology can be an effective sustainability-supportive tool when used in conjunction with the institutional culture of sustainability, environmental education and strategies for engaging in sustainable behavior.

Rogers' Diffusion of Innovations Theory and Ajzen's Theory of Planned Behavior are both appropriate theories to use to explain the findings. Rogers' theory suggests that students have been progressing from the awareness and persuasion phases towards the implementation phase where sustainable environmental behavior is implemented in their daily lives, but many students are not yet at the implementation stage. Likewise, the Theory of Planned Behavior by Ajzen indicates that even though students have positive environmental attitudes, their sustainable behavior is still affected by social norms, institutional facilitation, and perceived behavioral control. Thus, enhancing environmental awareness is not enough to ensure sustainable environmental behavior if the universities do not offer supportive environmental contexts and opportunities to learn about sustainability.

The study's findings are of practical importance in the UAE context, as sustainable development, smart transformation and environmental innovation are becoming more and more prevalent in the country. Sustainability has been made a UAE national priority with a series of environmental and technological projects. Hence, UAE universities are expected to play an active role in meeting the UAE sustainability goals by incorporating environmental responsibility into digital learning systems, institutional culture and student activities. According to the results of the present research, the role of smartphone use and digital technology in the effort to achieve these national sustainability targets is quite significant, in terms of strengthening environmental awareness and making students at universities more aware of environmental responsibility.

8. Recommendations

The following recommendations can be put forward based on the results of the study for advancing the role of smartphones in supporting environmental sustainability among university students. Universities' first task is to embed principles of environmental sustainability into their digital curricula and technology-supported educational systems more and more. Sustainability education can go beyond theory to achieve real sustainability engagement that can inspire students to implement sustainable practices in their everyday lives. It is crucial for universities to create practical sustainability programs that are supported by the use of smartphones including applications that are environmentally aware, digital sustainability competitions, e-waste collection points, reminders to recycle and smart transportation campaigns. Sustainability should also be introduced in the digital education so that students will not only be aware of it but also act according to it. Universities can also promote involvement by offering incentives, environmental clubs run by students and regular digital campaigns on recycling, energy conservation and responsible use of smartphones.

Second, universities need to create specific sustainability-related smartphone applications that will give students advice on environmental issues, recycling, saving energy, etc., and sustainability-related educational materials. These can reinforce students' environmental awareness, while also fostering hands-on engagement with environmental issues, using interactive and tech-enhanced learning.

Third, education should also be in the form of digital environmental competitions, environmental campaigns, and environmental activities driven by smartphones, which will encourage students to participate in environmental activities. The results highlighted high student acceptance of digital environmental competitions and technological initiatives with a sustainability focus, showing that students are very receptive to interactive and technology-based approaches to sustainability that are related to their digital lifestyle.

Fourth, universities can foster environmentally responsible actions toward technologies through awareness campaigns on electronic waste management, smartphone recycling, and energy saving and sustainable digital consumption. Setting up electronic recycling drop-off

facilities on university premises could play a major role in the decrease in electronic waste and in the promotion of environmentally friendly disposal habits among students.

Fifth, universities should promote the rational use of energy when using smartphones and reduce unnecessary replacement of smartphones. The campaigns for increasing awareness of sustainability should highlight the negative environmental impacts of the overuse of technology and urge students to adopt more environmentally friendly lifestyles when using technology.

Sixth, smart transportation applications, ride-sharing systems and environmentally friendly transportation technologies that can lower carbon emissions and foster sustainable transportation practices should be further promoted in the university community. These types of efforts would be in line with the UAE's sustainability goals and have a positive impact on reducing the environmental impact of transportation.

Finally, the study suggests that further research is needed in the relationship between digital technologies and environmental sustainability in various learning environments and in various groups. The impact of sustainability interventions with smartphones, environmental campaigns as digital tools and technology-assisted behavioral interventions in promoting longer-lasting sustainable environmental behaviors among university students could also be explored in future studies.

Limitations

There are some limitations to this study. The first is that causal inferences are not possible in a cross-sectional correlational design, so the results should be interpreted as associations, not as evidence of a causal relationship between the usage of smartphones and sustainable environmental behavior. Secondly, the study was based on self-reported questionnaire data, which may be influenced by social-desirability bias and the subjective perception of the participants. Third, the sample only consisted of 90 students from a single university, and the results cannot be generalized to other universities or other students. Fourth, the study was based on the Diffusion of Innovations Theory and the Theory of Planned Behavior, but the constructs of these theories were not directly measured. Future research should employ more representative and larger samples, longitudinal or experimental designs, and theory-based scales that are validated. In addition, the voluntary non-probability recruitment procedure, unavailable invitation denominator, and missing age, discipline, year of study, and campus distributions limit representativeness and prevent calculation of a response rate.

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Abbreviations

UAE	United Arab Emirates
ICT	Information and Communication Technology
AI	Artificial Intelligence
UNESCO	United Nations Educational, Scientific and Cultural Organization

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