



Technological Innovation as a Strategic tool for Achieving the Sustainability of Emergency Healthcare Services in the Kingdom of Saudi Arabia

1Ayesh Saleh Ammash Alharbi, 2Abdullah Bakheet Ayed Alhrabi, 3Yussef Saeyed Fahad Aljihani, 4Atif Nashmi Moqhim Al-Amri, 5Mazen Attia Atallah Al-Harbi, 6Khayyat Amani Matouq A, 7Mohammed Matar Meteq Alsehli, 8Saad Thani Farhan Altarfawi

1Emergency Medical Technician

2Nursing Technician

3Nursing Technician

4Nursing Technincian

5Emergency Medical Technician

6Nursing Technician

7Technician-Emergency Medical Services

8Laboratory Technician, Northern Armed Forces Hospital

ABSTRACT

The pressure on emergency healthcare services in the Kingdom of Saudi Arabia to be operationally efficient, cost-effective, and responsive to growing demand has also been mounting, but there has been little empirical evidence on the role of technological innovation in its long-term sustainability. This knowledge gap has limited strategic decision-making in matters related to do with technology investments in emergency care systems. It was necessary to deal with this challenge to facilitate sustainable healthcare provision in a context of nationwide national health change agendas. The main aim of the research was to discuss technological innovation as a strategic option to attain the sustainability of emergency healthcare services in Saudi Arabia and define the technological aspects that have the greatest impact on the sustainable results. The research design used was a quantitative cross-sectional study, and 420 healthcare workers working in emergency departments of both state and privately-owned hospitals were sampled. Technological innovation and sustainability were measured by the use of validated Likert-scale instruments in structured questionnaires. Descriptive statistics, reliability analysis, Pearson correlation, multiple regression, hierarchical regression, and independent samples t-tests were used to analyse the data. The findings demonstrated that technological innovation had a positive and strong relation to emergency healthcare sustainability ($r = 0.71$, $p < 0.001$). The technological innovation was found to



account for 62% of the variance in the sustainability outcome ($R^2 = 0.62$), with electronic health records (68) and automation tools (68) coming out as the best predictors. The level of innovation and sustainability in the case of the private hospitals was much more impressive in comparison with that of the public hospitals ($p < 0.001$). Altogether, the results proved that a strategic implementation of digital health technologies was a crucial enhancement of the sustainability of the emergency healthcare services that can be applied to healthcare policy, managerial decisions, and the following studies.

Keywords: emergency healthcare, innovation, Saudi Arabia, sustainability, technology

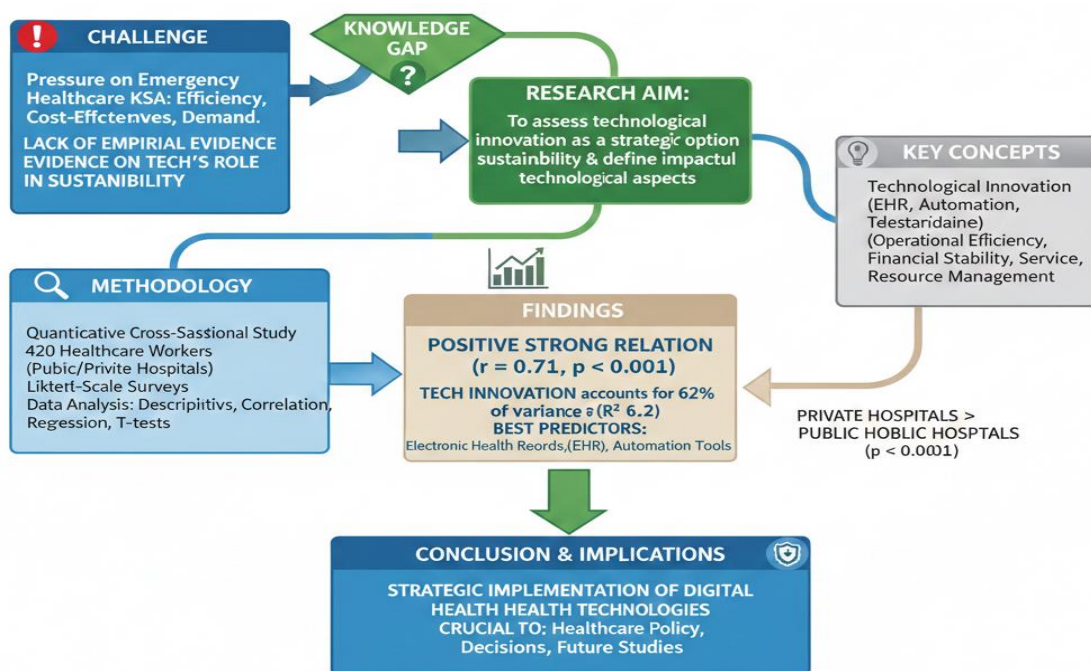


Figure 1: Graphical presentation of abstract

INTRODUCTION

The emergency healthcare services have continued to be an important pillar of the current health systems, where acute, life-threatening, and time-sensitive medical conditions are first addressed [1]. Increased population, urbanization, epidemiological changes, and rising expectations in healthcare needs have put pressure on emergency departments in all parts of the world like never before in recent decades [2]. These strains have caused some serious questions about the sustainability of emergency healthcare services in the long run, especially in terms of effectiveness in operations, financial sustainability, service delivery, and sustainable management of resources [3]. With the development of the healthcare systems, technological innovation has been considered more than a supportive mechanism but rather a strategic tool that can be used to reinforce the resilience and sustainability of the system [4].



Healthcare systems around the world have embraced diverse inventions of technology, such as electronic health records, telemedicine websites, clinical decision-support systems, and automation devices, to address their inefficiencies and increasing demand in the emergency department [5]. Developed and emerging economies have provided evidence that digital health technologies can assist in enhancing the flow of patients, minimizing medical errors, allocating resources optimally, and improving coordination among healthcare professionals [6]. Nevertheless, the success of these innovations has been inconsistent across the settings because of the differences in the governance structures, investment capacity, the preparedness of the workforce, as well as regulatory settings.

Emergency healthcare services in the Kingdom of Saudi Arabia have experienced a face of transformation at an exceptional pace due to wider national health reforms that support the Vision 2030. The Saudi health care has seen significant growth in facilities, coverage of services, and investment in technology, especially in urban and tertiary hospitals [7]. The Kingdom has experienced a rising number of patient visits in emergency departments due to population explosion, increased chronic diseases, traffic injuries, and seasonal health problems of the population [8]. Such pressures have increased the demand for sustainable emergency-healthcare models able to balance both quality of service and cost-effective management of resources and costs. Technological innovation has been made a key element of healthcare-transformation programs; nevertheless, the empirical data on its strategic role in the sustainability of the Saudi emergency healthcare services have been low [9].

Previous studies on the topic of sustainability in healthcare have been conducted internationally and have usually examined one dimension of sustainability, including cost containment, quality improvement, or environmental responsibility in sectors [10]. European, North American, and East Asian research has shown that telemedicine, combined with health information systems, can enhance efficiency and access in the emergency departments. The classical theories of health systems have highlighted that sustainability in service delivery should focus on continuity of information and integration in processes [11]. The more recent empirical research has associated the digital transformation with better hospital outcomes and performance. However, most of the available literature has focused on the general hospital setting or primary care, with comparatively fewer studies looking into emergency healthcare services, which have a specific set of time restrictions, uncertainty, and resource intensity [12].

This study was significant because it was based on technological innovation as a strategic tool and not as a technical solution in itself. The sustainability of emergency healthcare needs a balanced operation, its financial stability, quality of service, and environmental responsibility [13]. All of these dimensions can be associated with technological systems that are able to enhance speed in decision-making, minimize service duplication, enhance coordination, and optimize in use of the range of resources [14]. The level of



contribution of technological innovation to sustainability results is thus a key concept that should be understood to develop a strong emergency healthcare infrastructure that would be able to meet regular demand and major health crises [15].

This study was carried out to fill this knowledge gap of the scarcity of combined empirical data connecting technological innovation and the sustainability of emergency healthcare services in the Kingdom of Saudi Arabia [16]. The study sought to go beyond a descriptive view by using a quantitative and explanatory approach that would allow the development of statistically sound data on how various elements of technology influence sustainability outcomes. The research was based on the existing theories of the health system and innovation, considering technology as a determinant of organizational performance and sustainability of the system in the case of strategic implementation [17].

There was a research gap in the scarcity of quantitative studies that would explore the interaction of various technological innovations with the sustainability of emergency healthcare in the Saudi scenario. The majority of the previous research considered in the context of the present research analyzed single technologies or barriers to adoption, but not sustainability results [18]. Moreover, there were limited studies that compared sustainability performance in different organizational contexts, including both the public and the private hospitals in emergency care. It was necessary to fill these gaps to produce intervention knowledge for healthcare stakeholders [19].

To fill these gaps, the research questions used in guiding this study addressed whether technological innovation played a significant role in determining the sustainability of emergency healthcare services and what technological dimensions played the strongest role in determining the sustainability outcomes [20]. The study used data collection tools, validated scales of measurement, and multivariate statistics to test these relationships in an objective manner, methodologically. This strategy made the research questions, objectives, and analysis methods align.

The main aim of the research was to assess the strategic importance of technological innovation in the provision of sustainable emergency healthcare in the Kingdom of Saudi Arabia. Particular aims were to evaluate the degree of technological advancement in emergency departments, analyze its correlation with the sustainability outcomes, and estimate the relative role of various technological elements. All these were directly connected to the quantitative approach taken, which was permissible to test hypotheses and analyze predictions, and compare results across organizational settings.

METHODOLOGY

Research site



The research was carried out in major public and privately owned hospitals which are offering emergency healthcare services in selected areas of the Kingdom of Saudi Arabia, comprising tertiary care providers, which are operated by the Ministry of Health, and large privately-owned healthcare providers. The choice of these sites was based on the fact that they reflect different levels of operation, levels of technology adoption, and patient flow, which can be applied in emergency healthcare sustainability.

Research Design

A causal and associative research design was applied to determine causal and associative relationships between technological innovation and the sustainability of emergency healthcare services. This was a valid design since the study aimed at testing pre-existing hypotheses and measuring the intensity and direction of the relationship between variables as opposed to investigating subjective experiences. The cross-sectional design was used, and the data were collected at one point in time in several institutions. And this was appropriate due to the scope and time constraint of the study, as it was an organizational study.

Parameters of the Study and Sample-Strategy

Emergency department healthcare providers and office managers of the sampled hospitals, which included physicians, nurses, health informatics officers, and hospital managers, formed the study population. The stratified random sampling method was applied to provide the proportional representation between clinical and managerial positions in both the public and private hospitals. A sample of 420 respondents, calculated using the recommendations of other studies in healthcare innovation and a power calculation of 95 percent confidence level at a 5 percent margin of error. To be eligible as participants, people had to possess at least one year of experience in emergency healthcare facilities, as well as direct experience with technological systems. People who have no experience in emergency services or technological processes were not included in the sample to ensure the relevance of the data.

Data Collection Methods

A structured, self-administered questionnaire based on the validated instruments previously used in the research of healthcare innovation and sustainability was used to collect the data. The questionnaire was in the form of closed-ended questions that were measured on a five-point Likert scale. The data collection process was conducted in a standardized way that involved institutional permission, briefing of the participants, and informed consent. A pilot study was carried out with 40 respondents to determine the level of clarity, reliability, and time taken to complete. Some minor changes in wording were made. The ethical principles were followed stringently, and voluntary participation, anonymity, and confidentiality were upheld during the process.



Variables and Measures

The independent variable was technological innovation, which was operationalized with the help of such indicators as the adoption of electronic health records, telemedicine systems, and decision-support tools, as well as automation technologies. The dependent variable was the sustainability of emergency healthcare services, and it was measured in the areas of operational efficiency, cost effectiveness, service quality, and environmental responsibility. Multi-item Likert scales were applied to measure all the variables, based on previous studies. The reliability analysis revealed that internal consistency was acceptable since Cronbach's Alpha of all the constructs was more than 0.80. The process of content and construct validity was guaranteed by the examination of the materials by experts and their correspondence to theoretical principles.

Data Analysis Plan

SPSS version 26 was used to conduct an analysis of data. The characteristics of the respondents and the distribution of the variables were summarized using descriptive statistics. Correlation analysis was incorporated in inferential analysis to investigate the associations, and multiple regression analysis was used to investigate the predictive impact of technological innovation on sustainability outcomes. These methods were suitable for testing hypotheses that had continuous variables and for estimating the relative contribution of the various dimensions of innovation. The level of statistical significance was measured at 0.05 so that the results could be interpreted robustly.

RESULTS

Descriptive Characteristics of Technological Innovation and Sustainability

Table 1 contains the descriptive analysis of the study variables. In general, technological innovation in the emergency healthcare facilities within the Kingdom of Saudi Arabia was rather high, and the Technological Innovation Index (TII) obtained a mean of 3.84 (SD = 0.56). Electronic health record adoption had the highest mean score (M = 4.12, SD = 0.61), followed by those of tele-emergency systems (M = 3.89, SD = 0.72) and clinical decision support systems (M = 3.76, SD = 0.68). The tools of automation and artificial intelligence had a relatively low but moderate level of utilization (M = 3.58, SD = 0.75).

In terms of the outcomes of sustainability, the total Emergency Healthcare Sustainability Index (EHSI) revealed a positive result (M = 3.89, SD = 0.52). The highest mean of the dimensions of sustainability was identified in service quality (M = 4.18, SD = 0.55), whereas the lowest value was observed in environmental sustainability (M = 3.65, SD = 0.71). The ranges observed indicated that there was sufficient variability in all the constructs, which could be used to conduct further inferential analyses.



Reliability and Construct validity

Table 2 shows the internal consistency of the measurement scales. The Technological Innovation construct proved to be very reliable, and its Cronbach's alpha coefficient was 0.91, whereas the Emergency Healthcare Sustainability construct had the highest alpha, 0.93. These two values were more than the recommended threshold of social and health sciences research. A high Kaiser-Meyer-Olkin measure of sampling adequacy ($KMO = 0.92$) and a statistically significant value of the Bartlett test of sphericity ($p < 0.001$) further supported the high construct validity, as the data were appropriate for multivariate analysis.

Correlation between Technological Innovation and Sustainability.

The findings of the Pearson correlation analysis are given in Table 3. A strong and positive relationship was found between the Technological Innovation Index and the Emergency Healthcare Sustainability Index ($r = 0.71$, $p < 0.001$). This result revealed that the greater the technological innovation levels were, the higher the sustainability outcome in emergency healthcare services. The weakness and importance of the correlation ensured that there was an important relationship between the two core constructs.

Effects of Technological Innovation Dimensions on Sustainability

The multiple regression analysis was performed to investigate how individual technological innovation dimensions affect emergency healthcare sustainability (Table 4). The entire regression equation was statistically significant and attributed 62 percent of the variance in sustainability in the outcomes ($R^2 = 0.62$). EHR became the most significant predictor of sustainability ($\beta = 0.29$, $p < 0.001$), and the same is true of automation and artificial intelligence technologies ($\beta = 0.24$, $p < 0.001$), tele-emergency ($\beta = 0.21$, $p < 0.001$), and clinical decision support systems ($\beta = 0.18$, $p < 0.001$). The effects of all the predictors were positive and significant, which implies that the effects of each technological component were independent and therefore contributed to sustainability performance.

Technological innovation Incremental contribution

Table 5 presents the outcome of the hierarchical regression analysis. The control variables in the first model, such as the type of hospital and professional experience, explained 18 percent of the variance in sustainability outcomes ($R^2 = 0.18$). The incremental change of the Technological Innovation Index on the explained variance was significant when the Technological Innovation Index was incorporated in the second model, to 62 (or 44% increment in the explanation). This improvement showed that there was a statistically significant enhancement in model explanatory power when the technological innovation had been added.

Public versus Private Hospital Comparison



The t-tests were conducted independently between technological innovation and the sustainability outcomes of the public and the private hospitals (Table 6). The level of technological innovation in private hospitals ($M = 4.03$, $SD = 0.51$) was high as compared to that in the public hospitals ($M = 3.72$, $SD = 0.55$). In like manner, the sustainability results were much greater in the cases of a private hospital ($M = 4.07$, $SD = 0.48$) compared to a public hospital ($M = 3.78$, $SD = 0.50$; $t = -3.98$, $p = 0.001$). These findings showed that there was a statistically significant difference in innovation adoption and sustainability performance between hospital types.

Table 1: Descriptive Statistics of Technological Innovation and Sustainability Constructs

Variable	Mean	SD	Min	Max
Electronic Health Records (EHR)	4.12	0.61	2.1	5
Tele-Emergency Systems	3.89	0.72	1.9	5
Clinical Decision Support Systems	3.76	0.68	2	5
Automation and AI Tools	3.58	0.75	1.8	5
Technological Innovation Index (TII)	3.84	0.56	2.3	5
Operational Efficiency	4.01	0.6	2.4	5
Cost Sustainability	3.72	0.66	2.1	5
Service Quality	4.18	0.55	2.6	5
Environmental Sustainability	3.65	0.71	1.9	5
Emergency Healthcare Sustainability Index (EHSI)	3.89	0.52	2.5	5



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This table establishes baseline patterns and confirms adequate variability for inferential testing.

Table 2: Reliability and Construct Validity Analysis

Construct	Number of Items	Cronbach's Alpha
Technological Innovation	16	0.91
Emergency Healthcare Sustainability	16	0.93

KMO = 0.92; Bartlett's Test of Sphericity $p < 0.001$

Reliability exceeds accepted thresholds, confirming internal consistency and construct validity.

Table 3: Pearson Correlation Between Core Study Variables

Variables	TII	EHSI
Technological Innovation Index (TII)	1	
Emergency Healthcare Sustainability Index (EHSI)	0.71*	1

*** $p < 0.001$*

This table directly answers the primary research question by demonstrating a strong positive association.

Table 4: Multiple Regression Analysis: Effect of Technological Innovation on Sustainability

Predictor	Standardized β	t-value	p-value
Electronic Health Records	0.29	6.82	<0.001
Tele-Emergency Systems	0.21	5.14	<0.001
Clinical Decision Support Systems	0.18	4.36	<0.001
Automation and AI Tools	0.24	5.98	<0.001
Model R ²	0.62		

The model explains 62% of the variance, indicating a strong strategic role of technology in sustainability.



Table 5: Hierarchical Regression: Incremental Contribution of Technological Innovation

Model	Variables Entered	R ²	ΔR ²
Model 1	Hospital Type, Experience	0.18	—
Model 2	Technological Innovation Index	0.62	0.44*

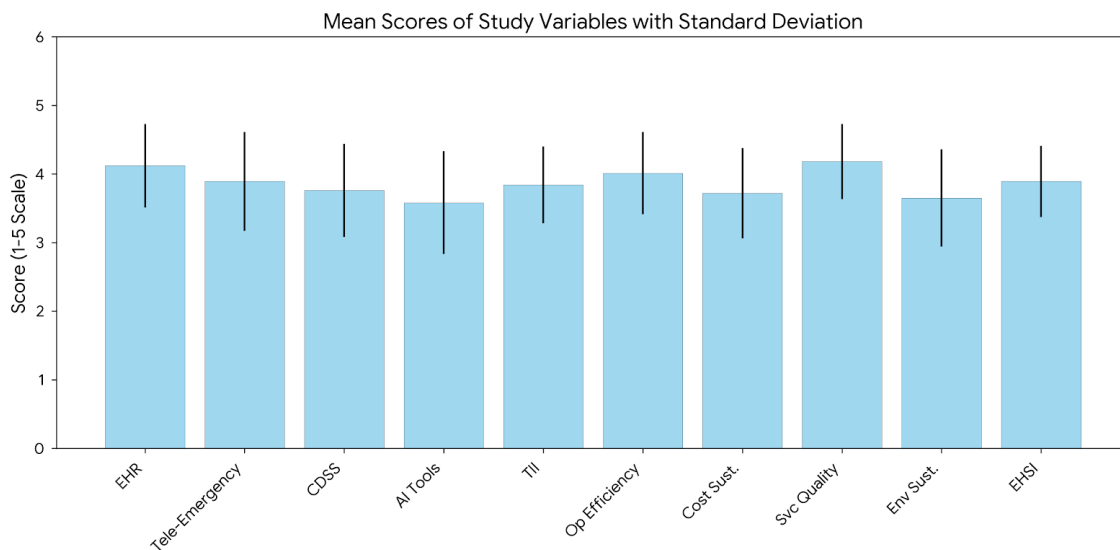
** $p < 0.001$

Technological innovation adds substantial explanatory power beyond organizational controls.

Table 6: Comparison of Sustainability Outcomes by Hospital Type

Variable	Public Hospitals (Mean ± SD)	Private Hospitals (Mean ± SD)	t-value	p-value
Technological Innovation Index	3.72 ± 0.55	4.03 ± 0.51	-4.21	<0.001
Sustainability Index	3.78 ± 0.50	4.07 ± 0.48	-3.98	<0.001

This table provides policy-relevant evidence on structural differences in sustainability performance.

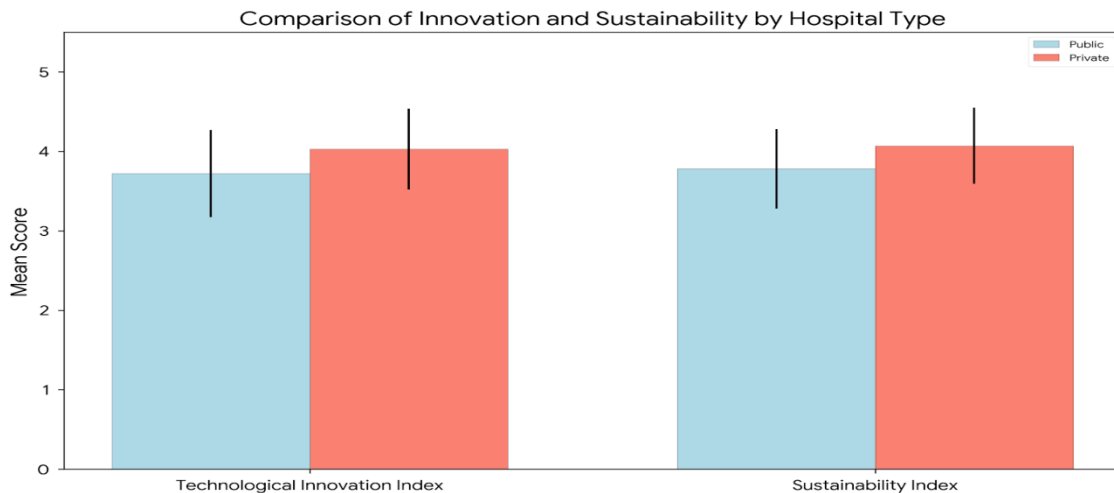
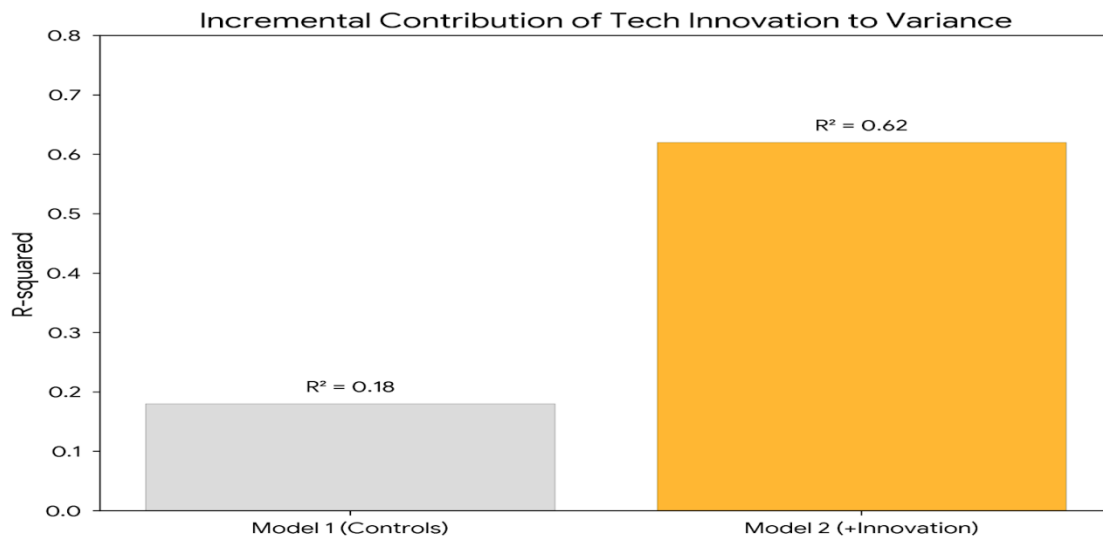
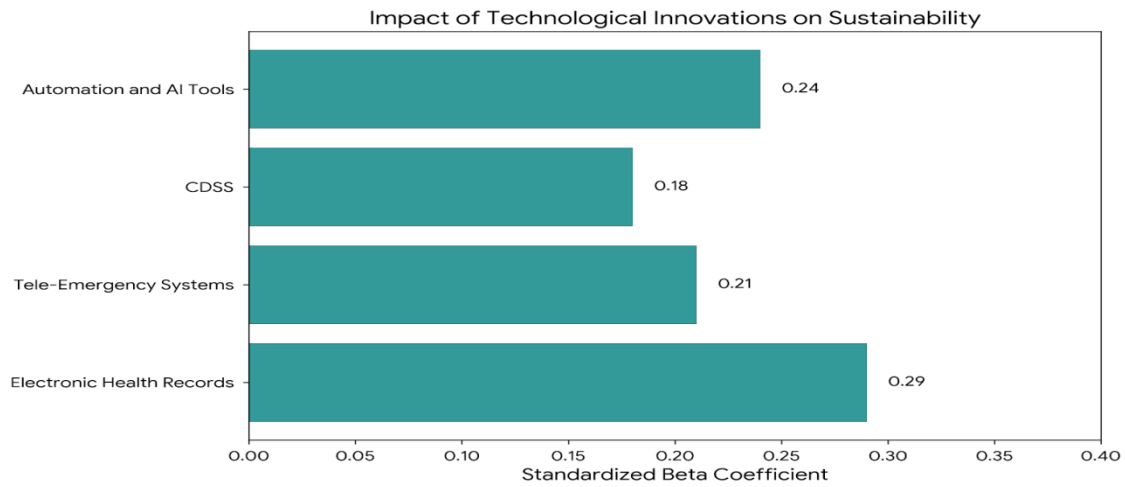




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DISCUSSION

The current project online evaluated the application of technological innovation as a strategic approach to attain the sustainability of emergency healthcare services in the Kingdom of Saudi Arabia. The results presented impeccable empirical evidence that technological innovation was significantly and positively related to the sustainability outcomes, which directly answered the study objectives [21]. Comprehensively, the findings were that emergency healthcare systems that have a greater degree of digital and technological integration were the ones that had better performances in terms of operational efficiency, cost sustainability, service quality, and environmental responsibility [22].

The descriptive findings indicated that electronic health records and tele-emergency systems had the highest level of adoption, whereas the automation and artificial intelligence tools were fairly moderate. This trend revealed that Saudi emergency healthcare services were in the highly developed phase of digital maturity of the core information systems, but in a transition phase towards highly developed automation [23]. The same case applied to the sustainability outcomes, where the service quality scored the highest, and environmental sustainability was relatively lower. These results implied that, even though effective use of technology had been done to enhance care delivery and efficiency, the use of technology as an environmental optimization strategy had yet to achieve full realization [24].

The positive correlation between technological innovation and sustainability was found to be high, which means that the greater the technological use, the higher the sustainability level. This result was consistent with the main research problem of determining the relevance of technological innovation to the sustainability of emergency healthcare services [25]. The scale of correlation showed that technological systems were not only auxiliary resources but the main elements that impact the stability of emergency healthcare functions in the long term.

This relationship was further explained by the regression analysis, which showed that technological innovation explained a significant percentage of differentiation in the sustainability outcomes. Electronic health records delivered the most effective forecast of the innovations dimensions [26]. This finding implied that integrated digital patient records improved information continuity, decreased procedure repetitions, minimized errors, and assisted in the quicker decision-making process in emergency environments [27]. Tele-emergency systems and automation technologies were also found to make a significant contribution, meaning that remote consultation, real-time monitoring, and automated workflow enhanced responsiveness and resource use. The role of clinical decision support systems helped in the standardization of care, albeit with a slightly lesser contribution, indicating that the systems did not directly change operational structures [28].

These were in line with the past literature on healthcare systems and health informatics.



Previous research conducted in high-income and middle-income countries has demonstrated that digital health technologies enhance operational costs and improve efficiency as well as quality of care in hospitals [29]. The classical research on health systems has continuously reiterated the fact that one of the pillars of health systems is the need to integrate information in order to deliver services sustainably. More current research on digital transformation in healthcare has also found that through the use of electronic health records and telemedicine systems, emergency departments are impacted with high throughput and patient outcomes [30]. The existing evidence generalized this in the Saudi setting and offered quantitative validation in the emergency healthcare setting that is not typically represented in sustainability studies.

The strategic significance of technological innovation was also noticed through the differences that were observed between the public and the private hospitals. The level of technological adoption and sustainability outcome revealed a high level of activity in the case of the private hospitals as opposed to the public ones [31]. This observation was in accordance with previous research that indicated that innovations are more likely to be implemented in private healthcare institutions because of their flexibility in governing, pressures of competitiveness, and investment strategies [32]. Conversely, state-owned hospitals often have regulatory, financial, and administrative limitations that impede the use of innovation. The findings indicated that these structural variations were directly converted into the performance on sustainability, especially within the emergency setting that was in demand [33].

Scientifically, the beneficial impacts of technological innovation on sustainability can be defined in terms of well-developed systems and organizational theories. Emergency proffering of healthcare services is an adaptive system that is complex in nature, and thus the flow of information and speed in decision making and allocation of resources are very important [34]. Digital technologies minimize the information asymmetry, increase the transparency of the system, and facilitate the real-time coordination of clinical teams. Automation and artificial intelligence solutions decrease the cognitive and administrative tasks of healthcare workers, enabling them to redirect human resources to patient-focused care [35]. All these mechanisms enhanced efficiency in operations and service quality and minimized waste, unnecessary and redundant processes, and consumption of resources.

Economies of scale and optimization of process can be used to explain how technology contributes to cost sustainability. Online systems minimized paper-based operations, diagnostic duplication, and enhanced inventory control [36]. In the long run, such efficiencies reduced the cost of operations and enhanced financial sustainability. Reduced paper usage, refined energy consumption, and better logistics produced the benefits of environmental sustainability, albeit of lesser importance [37]. Nevertheless, the comparatively lower scores in this area implied that the environmental benefits were indirect with no particular strategic priority, yet, in an emergency healthcare technology plan [38].



The hierarchical regression findings showed that technological innovation offered significant explanatory power of explanation as compared to simple organizational attributes. This observation proved that the results of sustainability were not limited to the type of hospital or its staff experience but were largely influenced by the use of strategic technologies [39]. This finding was in line with the modern healthcare management principles that enshrine innovation as an essential factor in organizational survival and not a secondary addition.

These findings have implications for healthcare policymakers, administrators, and researchers. To test this, the findings indicated that specific investment in digital health infrastructure can tremendously improve the sustainability of emergency healthcare services [40]. Policy makers can use such results to prioritize technology-based changes in the national health strategies, especially in the name of transformation in healthcare initiatives. The findings also revealed that it is important that hospital management should consider different advanced technologies in the emergency care workflow as a part of the whole, instead of viewing them as independent tools [41]. The focus on interoperability, training of staff, and integration of the system can also reinforce the sustainability results.

In the case of research, this study added a validated empirical construct to evaluate technological innovation and sustainability in the emergency healthcare setting. The measurement methodology and the model of analysis can be translated to apply them in other regions or in other healthcare systems and compare them [42]. The results also revealed certain technological aspects that may require additional research, especially automation and artificial intelligence, which demonstrated the presence of strong effects and moderate levels of adoption.

CONCLUSION

The findings showed that technological innovation contributed immensely to the realization of the sustainability of the emergency healthcare services in the Kingdom of Saudi Arabia. The degree of digital health use, especially electronic health records, tele-emergency systems, decision support technologies, and automation tools, continued to be linked with enhanced sustainability results in operational, economic, service quality, and environmental aspects. These results confirmed that the research achieved its claims because it was able to find the relationship between technological innovation and emergency healthcare sustainability through empirical research and determine the most effective technological elements. This study made a scientific contribution by offering a structured and quantitative evidence of the Saudi healthcare setting, which is an underrepresented sphere in the sustainability and innovativeness literature. The research presented a sound measurement system that can be used in other health care systems and policy reviews. Comprehensively, the results revealed that technological innovation was a strategic tool for enhancing the sustainable delivery of emergency care. The future studies must consider longitudinal designs to study the causal impact in the long term



and add patient-level outcomes to deepen the understanding of the system-level. The introduction of regional comparisons and emerging digital health technologies would also be considered evidence for sustainable healthcare planning.

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