IJBB
International Journal of Biotechnology and Biomedicine
Vol. 1 No4; December 2024 https://doi.org/10.31674/ijbb.2024.v01i04.005

The Tech Prescription: Innovating Sustainable Health

Sania Asad[1],[*] Amiya Bhaumik[1], M. Khadija Khan[2]

[1]Department of Business and Accountancy, Lincoln University College, Malaysia
[2]Department of Economics, National College of Business Administration & Economics, Pakistan

Corresponding Author's E-mail: saniaasad51@gmail.com

Article received on 9th April 2025
Revision received on 30th April 2025
Accepted on 30th April 2025

Abstract
Although the technological revolution continues to restructure the healthcare realm, the adoption of sustainable health solutions still remains a recurring challenge, especially in Pakistan. This study interrogates the role of technological advancement in sustainable health solutions while integrating health promotion as a mediating factor. The selection of the firms used for this analysis is based on the firm's active amalgamation of technological advances in healthcare provision. Data from five major healthcare firms have been analyzed for the years 2019-2023 by using the techniques of panel regression and mediation analysis. Results of the study explain that tech-enabled innovations like digital health, telemedicine, surgical robotics, automation, predictive analysis, and 3D printing have a positive significant impact on sustainable health solutions including eco-friendly waste disposal, reduction in carbon emissions, the transition from cure-based approach to preventive approach and healthcare accessibility. Furthermore, the study predicts a significant partial mediation highlighting that health promotion mediates the relationship between tech advances and sustainable health solutions. This suggests that health promotion strategies can be beneficial in augmenting the impact of tech evolution. In spite of the potential technology possess, there are still numerous challenges like digital illiteracy, public skepticism, lack of infrastructure and regulatory voids that hinder the application of tech advances in the region. In order to amplify the adoption of technological transformation and well-structured policies, investment in digital infrastructure and comprehensive personnel training is pivotal. This research reinforces the exigency of incorporating health promotion strategies in order to attain sustainable health outcomes. The gap between technological potential and legitimate health outcomes can be bridged by the integration of health promotion, specifically in developing economies. The findings of the study offer valuable insights for stakeholders endeavoring to deploy tech-enabled, sustainable and equitable health solutions.

Keywords: Technological Advancement; Sustainable Health Solutions; Health Promotion; Artificial Intelligence; Sustainability

Introduction

Despite rigorous technological advancement in the healthcare sector, accomplishing sustainable health solutions still occurs as an undermining challenge. Although Artificial intelligence, telehealth, mobile health applications and smart healthcare environments have

revamped the execution of healthcare facilities, there is no clear consensus on how these innovations could be implemented effectively in order to maximize their influence on health promotion and long-term sustainability.

Global health disparities have continued to rise despite massive technological progress. The rising prevalence of chronic illness, obesity, mental health disorders and environmental degradation signifies the gap between the potential of technological advances and legitimate health outcomes (Hameed *et al.*, 2024). This challenge is certainly more apparent in Pakistan, where healthcare disparities are saturated in spite of the significant increase in digital healthcare technologies (Zahid, 2023). Pakistan faces prominent hurdles in incorporating technological solutions pertaining to lack of infrastructure, varying levels of digital literacy and immense regulatory gaps (Kazi *et al.*, 2020). Moreover, the absence of compliance and standards concerning sustainable development goals (SDGs) has hindered the implementation of sustainable models in many healthcare organizations (Sayani *et al.*, 2025). Even though technological advancement can transfigure sustainable health solutions their success is proportional to how constructively health promotion expediates their adoption and incorporation (Khowaja *et al.*, 2011). Hence, there is an urgency to figure out how health promotion mediates the relationship between technological advances and sustainable health solutions particularly in the healthcare sector of Pakistan. The focus of the study is to ensure that technological innovations are addressing the issues related to health disparities, social equity, promotion of equitable access and long-term sustainability in the context of Pakistan.

Technological advancements have prominently redesigned the structure of the healthcare sector. The impact of technological advancement is expected to expand in the coming years. Technological advances like Artificial Intelligence, telehealth, mobile health applications, robotics and smart healthcare environments are driving the gear of healthcare sectors towards preventive healthcare models rather than traditional cure-based approaches. The Global Smart Hospital market is expected to reach an appreciation of $148 billion by the year 2029 (Huber, 2025). AI-driven technologies like machine learning, and big data analytics can help to make informed decisions based on early disease detection, precision medicine, and systematic resource allocation. This can contribute to sustainable health outcomes leading to waste reduction and optimized healthcare provision (Kim *et al.*, 2021). Furthermore, mobile health applications and wearable smart devices stimulate preventive measures, self-monitoring, and self-management of chronic diseases which reduce hospital dependency, lowering the burden of hospital infrastructure and providing equitable access to rural populations (Gentili *et al.*, 2022). Technological evolution presents notable opportunities for improving sustainability, efficiency and patient outcomes in the healthcare sector.

Health Promotion is said to be the improvement of individuals and communities by taking control over their well-being by recognizing the root causes of the ailment. Health promotion refers to helping people stay healthy by providing them with the right kind of knowledge in order to prevent a disease in the first place instead of treating it after it happens. Health promotion emphasizes equitable access, preventive healthcare models and social interventions to demonstrate a sustainable healthcare approach (World Health Organization WHO). Education and awareness are some of the most effective promotion techniques that facilitate the adoption of technological advances in healthcare systems. Most of the underprivileged regions are still unaware of digital health technologies like telehealth, AI-driven diagnostics and mobile health applications. In order to address these issues digital health literacy initiatives,

community awareness programs, and public health campaigns can be conducted in order to bridge this gap and ensure that people understand, trust and utilize technological advances effectively (Kim *et al.*, 2021). In addition to this health promotion can also vitalize behavioral changes, which can lead individuals to incorporate health-related technologies like smart health watches into their day-to-day lives. Health promotion can be useful in teaching individuals about data interpretation in order to track their fitness through wearable gadgets (Zhang *et al.*, 2024).

The effectiveness of technological advances in improving healthcare sustainability depends on how well these advances are incorporated into public health initiatives. Health promotion is one of the most significant mediators ensuring that these technological advances have a reach towards the deliberate population. Certifying that technological advances contribute toward long-term sustainable and equitable health solutions (Dilanchien *et al.*, 2024). Initiatives like telemedicine, mobile health clinics, community-based health centers, universal health coverage initiatives, low-cost medication, vaccination and public health campaigns, mental health and well-being programs, fair wages and safe working conditions, digital training programs and training of local *healthcare* workers can improve the *healthcare* accessibility but the success of all these healthcare initiatives depends on how well they are being incorporated in the system.

Health promotion techniques leverage technological tools in order to prevent diseases, promote personalized healthcare regimes and enhance environmental sustainability (Hussain *et al.*, 2024). Health promotion enhances the impact of technological advances like blockchain and health data security by training patients regarding data ownership, building their trust in digital health systems and making sure that *blockchain* records are inclusive for all communities including the marginalized. This will help to keep up with the continuity of records in different healthcare systems reducing the workload of healthcare workers (Selvaraj, 2024). Encouraging the acceptance of 3D-printed prosthetics can be carried out by promoting them to amputees, and educating them about the affordability and potency of 3D limbs (Wu & Luo, 2019). Educating and training healthcare personnel regarding robotic surgeries can enhance the local health providers' morale by providing them with equitable access to technological upgradation (Kruse *et al.*, 2021).

While advocating for telemedicine platforms health promotion can produce a mediation effect through digital literacy programs, educating patients about the usage of mobile health applications contributing to sustainable health solutions with regard to increased healthcare access, reduction in hospital congestion, reduced in-patient visits leading to a decrease in carbon footprint generated due to fuel consumption and a huge decrease in paper and biomedical waste (Vazquez *et al.*, 2024). Health promotion through public health campaigns can address risk-population to undergo AI-based screening, inducing AI-based predictive analysis for an early diagnosis. This can reduce last-stage disease detection, decrease healthcare costs and enhance healthcare solutions for individuals (Clark *et al.*, 2021). Healthcare promotion can integrate wearable data in schools in order to encourage physical and sports activities. This can be achieved by introducing wearable devices like fitness trackers, smartwatches, and heart rate trackers resulting in lowered obesity rates and increased fitness levels (SBToolkit, 2024).

Although there are innumerable benefits of technological advances in the healthcare sector there still exists crucial challenges hindering their potent implementation. One of the major

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challenges is inequitable access to technology, the lack of digital infrastructure and other financial resources remains the core reason for digital illiteracy in Pakistan (Fayez *et al.*, 2024). In order to utilize advanced healthcare facilities, the bridge of this digital divide needs to be fostered by implementing government policies, affordable healthcare solutions, and awareness regarding the use of technology in Pakistan.

Integrating technological advances into health promotion strategies for sustainable health outcomes presents several challenges in the context of Pakistan. For instance, healthcare in Pakistan has limited digital infrastructure causing a hindrance to introducing telemedicine platforms. The rural population of Pakistan is generally low-income groups having limited or no access to smartphones or even the internet in some cases. This leads to the creation of a digital divide and health disparities among people. Some communities in the region have strong trust issues due to which they prefer in-patient visits rather than consulting telehealth platforms. The gap between the public and private healthcare sectors of Pakistan makes it difficult to strive for widespread smart healthcare solutions (Ittefaq & Iqbal, 2018). Hence conducting this research is of utmost importance with regard to Pakistan as technological intervention is the only way through which sustainability, affordability, efficiency and accessibility of healthcare solutions could be achieved in this region.

Literature Review

Tech innovations have reshaped the healthcare sector by incorporating accessibility, efficiency and accuracy in their healthcare models (Topol, 2019). The forefront of digital transformation in the healthcare sector is smart healthcare environments, mhealth, telemedicine and AI-driven innovations (Jiang *et al.*, 2017). Clinical decision-making, enhanced early disease detection and reduced misdiagnosis are the byproducts of AI-driven diagnostics (Ngiam & Khor, 2019). Remote consultations facilitated by telemedicine have served as a bridge between healthcare providers and patients specifically in underprivileged areas (Kruse *et al.*, 2016). Chronic conditions like diabetes and cardiovascular diseases can be monitored using mobile health applications (WHO, 2019). Mhealth applications provide real-time health data leading to preventive healthcare and personalized medical interventions (Lee *et al.*, 2023). Patient-centered care can be enabled by the usage of smart healthcare environments, wearable gadgets and devices integrating the Internet of Things followed by continuous monitoring (Al-Rawashdeh *et al.*, 2022). Despite all these advances in technology, low- and middle-income countries like Pakistan still face issues to ensure long-term equitable health access (Kazi *et al.*, 2020).

Machine Learning (ML) techniques can ensure disease forecasting and predictive analysis leading to the prediction of the occurrences of disease breakouts. This allows healthcare providers and policymakers to anticipate a health crisis and devise targeted interventions to mitigate its long-term effects. The operational efficiency of healthcare systems can be enhanced using machine learning. Admission rates of patients, staff schedules and equipment maintenance records are all streamlined due to machine learning, contributing towards cost reduction. Meaningful insights from clinical notes can be extracted by using Natural Language Processing (NLP). This helps in understanding patients' histories and supports research-driven decision-making. ML can also help in fraud detection carried through insurance claims and false billings. This contributes to maintaining the security and privacy of patients, ensuring compliance with regulatory frameworks and safeguarding confidential data. Applications of

machine learning in genomics analytics offer insights into genetic mutation, susceptibility of diseases and treatment response leading toward precision medicine which has been a game changer in targeting genetic diseases (Sarker, 2024).

Deep Learning (DL) plays a significant role in expediting drug discovery. The drug development process can be enhanced by using the applications of deep learning. This contributes to the faster marketing of novel therapeutics. DL models can be applied to understand and analyze behavioral patterns which can help in the identification of early signs of mental illness leading to personalized mental health support for individuals (Kaul *et al.*, 2022). Electronic Health Records (EHRs) have streamlined the administrative processes in the healthcare sector improving overall efficiency (Adeniyi *et al.*, 2024). The amalgamation of AI and Medical Imaging Processing (MIP) has maximized precision ensuring timely and speedy diagnosis. Virtual Health Assistants (VHAs) and chatbots have increased patient engagement by providing human-like interactions related to any healthcare information. In times of global health crises, these chatbots and VHAs can provide immense support by delivering accurate information which can reduce unnecessary hospital visits leading to reduced hospital congestion. AI-based robotic surgeries have changed the landscape of surgical intercession. The robotic systems are designed to perform intricate moves with utmost accuracy as compared to the human hand. This allows incisions to be precise benefiting delicate and complex procedures in order to reduce post-surgery trauma and ensure fast recovery of the patient (Balakrishna & Solanki, 2024).

Environmental sustainability and healthcare accessibility are all prioritized by sustainable health solutions (Huang *et al.*, 2021). An evident decline can be witnessed in hospital congestion, medical waste, paper waste, carbon footprint and energy consumption by integrating Artificial Intelligence, Internet of Things and telehealth in healthcare sectors (Naik *et al.*, 2022). Secured patient data, improved transparency and seamless exchange of information throughout the healthcare departments have only become possible due to blockchain technology (Andrada, 2024). Predictive analysis, improved supply chain efficiency and an overall decrease in environmental waste are derivatives of sustainable healthcare solutions, contributed through technological innovations (Dewasiri *et al.*, 2025). AI-driven algorithms optimize operations in healthcare, streamline inventory management, assist in energy conservation through solar-powered hospitals, supporting Sustainable Development Goals (Koebe, 2025). However, in order in order to achieve sustainable health solutions in Pakistan addressing the healthcare disparities is of crucial importance (Liaqat *et al.*, 2025). Limited infrastructure, regulatory gaps and resistance to digital transformation are the significant barriers that restrict the implementation of sustainable healthcare models in the region (Khalil, 2024). Moreover, the rural population of Pakistan is skeptical of digital literacy and is still struggling to build trust in AI-driven healthcare services. In order to address these challenges, the region needs to have a targeted health promotion strategy for educating communities, building trust in digital health and ensuring unbiased access to technological solutions (Zanobini *et al.*, 2024).

Health promotion illustrates its significance by bridging the gap between the development of sustainable health solutions through tech innovations. Prior literature is evident that technology adoption is significantly influenced by digital health literacy while digital illiteracy works as a barrier to the integration of mhealth platforms and telemedicine (Coleman, 2020). Public health campaigns and community awareness initiatives have been an instrumental source for people

to accept technological interventions. In resource-limited settings, chronic disease management and vaccination rates have been enhanced due to mobile-based education programs (Aliyu *et al.*, 2024). According to the Health Belief Model, individuals who understand the benefits and have received adequate training in digital health solutions are more likely to embrace such solutions (Alyafei & Easton-Carr, 2024). In Pakistan exacerbation of disparities in healthcare is due to a lack of structured health promotion strategies which hinders the implementation of digital healthcare services (Kazi *et al.*, 2020). Health promotion strategies emphasize digital inclusivity and trust facilitating the adoption of technological innovations among the public. Health literacy initiatives, community awareness programs and proper communication channels regarding digital health solutions can eradicate the resistance against AI-driven technological solutions like telemedicine, and wearable gadgets (Esper *et al.*, 2024). Furthermore, Health promotion strategies are crucial for highlighting the need to understand the importance of data privacy, patient security and ethical use of healthcare instruments in order to ensure that technological innovations are not used immorally and do not cause harm to any community especially the marginalized (Lupton, 2014).

In order to achieve equitable and sustainable health outcomes government subsidies, strategic implementation of digital *healthcare* policies and digital inclusion initiatives should be implemented (Chidambaram *et al.*, 2024). Due to a lack of standardized protocols and inconsistent regulatory frameworks for AI-driven health solutions, digital health policies in Pakistan remain fragmented (Iqbal, 2024). These gaps can be bridged by applying an approach that is multisectoral comprising integration of government policies, private sector investment, technological implementation and adequate health promotion strategies. This can lay a basis for the deployment of a sustainable healthcare system in Pakistan (Farhat *et al.*, 2024). A structured road map for achieving equitable and long-term healthcare sustainability can be accomplished through aligning health initiatives with Sustainable Development Goals (SDGs) specified by the United Nations Organization (United Nations, 2023).

Theoretical Framework

This study is primarily focused on the theories of Fred Davis's Technology Acceptance Model first developed in 1989 (Masrom, 2007) and Health Promotion Theory introduced by WHO in the Ottawa Charter 1986 (Nutbeam & Kickbusch, 1998). These explain the dynamics among health promotion, technology advancement and sustainable health solutions. These theories present an inclusive understanding of how tech innovations when supported by health promotion strategies can lead to sustainable, accessible and equitable health solutions, particularly in settings that are resource-constrained like Pakistan.

According to the Innovation Diffusion Theory developed by Rogers in 2003 (Wani & Ali, 2014) and the Sustainable Development Framework (WHO, 2020), tech innovations in healthcare have extensively transformed healthcare delivery. Technologies like telemedicine, advanced AI, and wearable technology have led to early diagnosis, preventive care models, and reduction of dependency on health infrastructure. However, the success of these innovations totally depends upon how well they are accepted, integrated, utilized and understood by both health practitioners and the public. As a consequence, sustainable health solutions are defined as health systems that are equitable, accessible, environmentally, socially responsible and cost-effective. Sustainability in healthcare systems is more achievable when paired with technological advancement. Thus, this proposes that:

H1: Technological Advancement has a significant positive impact on sustainable health solutions.

As articulated by the World Health Organization (WHO) Health Promotion Theory emphasizes that the root cause of ill health is lack of awareness, lack of equitable access and health disparities. The theory suggests that these issues can be addressed through informed actions, supportive environments, community empowerment and public policy. By enforcing behavioral change, raising awareness and community engagement, health promotion can bridge the gap between the development and implementation of tech innovation, thereupon guaranteeing that health solutions are accessible, equitable, efficient and sustainable. Perceived utility and ease of usability are some of the major factors that determine the adoption of technology. Lack of digital literacy, infrastructure and resistance due to socio-economic cultures in Pakistan are the major causes of hindrance to tech adoption. Hence, health promotion initiatives are utmost for ensuring anticipated effectiveness and usefulness. This suggests that:

H2: Technological Advancement has a significant positive impact on health promotion.

Furthermore, this study integrates the components of the Health Belief Model (Champion & Skinner, 2008). According to HBM if individuals are made to understand the benefits of preventive health, early detection of diseases and self-monitoring they are more likely to accept and integrate digital health solutions in their day-to-day lives. This highlights the importance of dedicated health promotion initiatives in reshaping people's perceptions toward the adaptability of sustainable health solutions. This posits that:

H3: Health Promotion mediates the impact of technological advancement on sustainable health solutions.

Methodology

This study employs a quantitative research design. The study investigates the impact of technological advancement on sustainable health solutions implemented in firms while health promotion is taken as a mediating variable. The research is conducted by utilizing secondary data collected through content analysis from sources subject to public availability.

Data Collection and Sampling

The selection of the firms used for this analysis is based on the firm's active amalgamation of technological advances in healthcare provision in the context of Pakistan. A purposive sampling technique is used in the study. The sample selection method is based on non-probability because the research is primarily focused on the healthcare sector. The focus of the research is on the firms that are affiliated with healthcare services and are actively engaged in technological advances and health promotion. The selection criteria are based on industry relevance and publicly accessible data. So, in compliance with the aforesaid criteria five major healthcare firms have been selected. The study analyzed five years of data (2019-2023) to scrutinize trends over the years. Data has been collected through content analysis techniques through the firm's websites, annual reports, PSX portal, sustainability reports and corporate social responsibility reports.

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Vol. 1 No4; December 2024 https://doi.org/10.31674/ijbb.2024.v01i04.005

Data Analysis Techniques

The data analysis has been conducted by using Python 3 through Jupyter Notebook in order to ensure optimized handling of panel data and statistical analysis. In order to investigate if health promotion mediates the impact of technological advancement on sustainable health solutions a mediation analysis has been conducted through panel regression (WG-Bootstrap). Since the data sample is small due to the limitation of tech advances only being incorporated in Pakistan's healthcare sector barely five years ago, the bootstrap technique followed by 5000 replications is used in order to ensure the robustness of results. Moreover, a Leave-One-Out Sensitivity Analysis has been conducted in order to verify the accuracy of the mediation analysis. Panel regression can be used for small samples if the estimation technique has been chosen wisely and interpretations are done cautiously (Santos & Barrios, 2011; Abonazel, 2016). The panel regression analysis is instrumental in conducting this analysis as it deals with the data across multiple firms over a period of time. Panel regression enhances the efficiency of estimates by accounting for unobserved heterogeneity, improving causal inference and capturing dynamic effects (Hsiao, 2005). Mediation analysis offers a nuanced interpretation of causal relationships by segregating total effects into direct and indirect effects (Mackinnon *et al.*, 2008). The significance of mediation has been tested by using the Sobel Test.

Measures

Technological advancement the independent variable, Health promotion the mediating variable and Sustainable health solutions the dependent variable all are measured through content analysis (Harwood & Garry, 2003) based on predefined keywords that are classified in into various categories (Appendix A, Table A). The operationalization of variables has been explained in Table 1.

Table.1 Operationalization of Variables

Variable	Measure	Operationalization
Technological Advancement	$TechAdv_i = \frac{\sum_{j=1}^{n} T_{ij}}{n}$	Where: $TechAdv_i$ = Score of technological advancement for firm i. T_{ij} = If technological factor j is present in the firm (1 if yes, 0 if no). n = Total number of technological advancement factors.
Health Promotion	$HP_i = \frac{\sum_{j=1}^{n} P_{ij}}{n}$	Where: HP_i = Score of health promotion for firm i. P_{ij} = If HP factor j is present in the firm (1 if yes, 0 if no). n = Total number of health promotion factors.
Sustainable Health Solutions	$SHS_i = \frac{\sum_{j=1}^{n} S_{ij}}{n}$	Where: SHS_i = Score of sustainable health solution implemented in firm i.

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		S_{ij} = If SHS factor j is present in the firm (1 if yes, 0 if no). n = Total number of Sustainable health solutions.

Results and Discussion

Correlation Analysis

The correlation matrix provides insight into the relationships between technological advancement, health promotion and sustainable health solutions. A moderate positive correlation (Table 2) can be seen between technological advancement and sustainable health solutions (0.66). This indicates that firm that tends to have a high level of technological incorporation tend to have more sustainable health outcomes. The correlation between health promotion and sustainable health solutions of 0.61 signifying that firms that are engaged in health promotion initiatives have a better chance of deriving sustainable solutions. A correlation of 0.65 between technological advances and health promotion indicates that health promotion can be driven by technological advancement.

Table 2 Correlation Results

	Technological Advancement	**Health Promotion**	**Sustainable Health Solutions**
Technological Advancement	1.00	0.65***	0.66***
Health Promotion	0.65***	1.00	0.61**
Sustainable Health Solutions	0.66***	0.61**	1.00

Note: (***) = Confidence Interval at 1%, (**) = Confidence interval 5%

Regression Analysis

Prior to formal analysis, the assumptions for multicollinearity and normality were tested. To test the normality of data Kolmogorov-Smirnov Test was conducted. The results highlighted values ranging from 0.3673-0.5127 showing the normality of data (Table 3). In order to test multicollinearity VIF values were used. The results of VIF indicate a value of 1.74 indicating that there was no issue of multicollinearity. These findings elaborate that the data meets the assumptions of regression analysis provided that the results derived from such data would be valid and reliable. The value for F-statistic (122.35, P-Value = 0.002, P-value = 0.011) for tech advances and health promotion respectively implies that the model is significantly a good fit.
Mediation analysis is generally conducted through Ordinary Least Squares Regression. Contrary to that we have chosen the panel regression technique in order to account for firm-level variations over a period of time. The data for this research is based on five firms that were not selected randomly but through purposive sampling over a period of 2019-2023. Since firms are selected based on fixed characteristics those characteristics may correlate with explanatory variables, violating the random effect model assumption. So, in order to conduct this research

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Vol. 1 No4; December 2024 https://doi.org/10.31674/ijbb.2024.v01i04.005

WG-Bootstrap seemed to be a more appropriate technique, the panel method was preferred due firm specific heterogeneity, temporal variations and enhanced statistical efficiency. Given these advantages, we incorporated panel OLS regression models with WG-bootstrap for the accuracy and robustness of the results.

Technological Advancement → Health Promotion

$$Health\ Promotion_{it} = \beta_1(TechAdv_{it}) + \alpha_i + \lambda_t + \varepsilon_{it}$$

The results indicate that a 1 unit increase in technological advancement exhibits a 0.6304 (P-Value < 0.01) increase in health promotion. Suggesting that hypothesis H2 is statistically positively significant. The value of R^2 explains that 85.41% of the variance is explained in health promotion due to technological advancement. These results are consistent with the findings stating that utilizing technological advances in the healthcare sector such as digital health platforms can give rise to increased patient engagement. Telemedicine and AI-driven monitoring can cause a significant decline in in-patient visits which may result in a reduced carbon footprint for the healthcare sector. Modern technology like mobile health applications can be used to educate about preventive measures that focus more on taking precautions rather than treatment (Hussain *et al.*, 2024). Technological advances can be used to minimize healthcare disparities in areas that are inaccessible like underdeveloped or rural areas, ensuring social equity (Ghafoor *et al.*, 2016). Technological advances can enhance sustainable innovations in health promotion, social policy and governance leading to improved justice, sustainability, efficiency and quality of healthcare services (Mohsin *et al.*, 2023).

Technological Advancement & Health Promotion → Sustainable Health Solutions

$$Sustainable\ Health\ Solutions_{it} = \beta_2(TechAdv_{it}) + \beta_3(HP_{it}) + \alpha_i + \lambda_t + \varepsilon_{it}$$

The results of direct effect indicate an overall significant positive impact of technological advances ($\beta_2 = 20.323, P - Value = 0.002$) on Sustainable Health Solutions (SHS) stating that hypothesis H1 is significant. This implies that technological advances have a direct significant impact on SHP irrespective of health promotion. These results are consistent with research conducted by Bianchini *et al.* (2023) suggesting that technological advances allow firms to strive for optimal labor division which can lead to increased operational efficiency by minimizing energy loss. Environmental production can be enhanced throughout the process of production if AI-driven technologies are incorporated into production processes. Firms can utilize their idle resources to pursue green production if digital technology is being implemented. Technological advancement can improve the information asymmetry in the firm enabling better corporate governance (Lu *et al.*, 2024). Technological advancement prompts firms to focus on the value-adding "Product + Service" corporate model fostering the firms to assume more substantial social responsibility (Tuyen *et al.*, 2023). Empirical testing is evident that technological advancement has a positive significant impact on a firm's sustainability. Digital Technology Innovation (DTI) can escalate sustainable solutions by recognizing social responsibility, green transformation, appropriate governance structure and policies (Su *et al.*, 2023).

According to the results obtained by implementing indirect effect, an overall significant positive impact of health promotion ($\beta_3 = 26.935, P - Value = 0.01$) on sustainable health solutions can be observed. This implies that firms prioritizing health promotion in their business models tend to have higher sustainable health outcomes. These results are supported

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by several peer-reviewed studies emphasizing that the healthcare sector plays a vital role in the reimposition and conservation of the environment. The healthcare sector seems to be extensively involved in producing gigantic amounts of medical waste, 24/7 operations of this sector make it one of the biggest consumers of energy (Zhu *et al.*, 2018). The global carbon footprint of the healthcare sector is said to be 4.4% of the world's total (Marimuthu & Paulose, 2016). Hence educating people through digital literacy programs, public campaigns and mobile education regarding these issues and the importance of applying techniques like telemedicine, remote monitoring of patients, and AI-driven data diagnostics can reduce both paper and medical waste in order to ensure a better and healthier environment.

Healthcare Systems that are primarily focused on anti-discrimination policies, patient satisfaction, human rights, policies against sexual misconduct, mental health, prevention programs, community awareness programs and disseminating health disparities tend to have a significant social impact which can increase employee morale and the firm's overall reputation. (Sepetis *et al.*, 2024). Firms that implement health and business ethics, embrace transparency in health promotion disclosure, protect patient's privacy and tackle cyber security threats tend to have a strong governance representation enhancing sustainable outcomes for the firms (Wienert *et al.*, 2022).

Table 3. Regression Results

Effect	Coefficient	Standard Error (SE)	F-stat	P-value
Technological Advancement → Health Promotion	0.630482	0.058284	154.28	0.0000
Health Promotion → Sustainable Health Solutions	26.935261	9.803193	122.35	0.01121
Technological Advancement → Sustainable Health Solutions	20.323614	5.989656	122.35	0.002398
Indirect Effect (X → M → Y)	16.982192	-	-	0.007744
Direct Effect (X → Y)	20.323614	-	-	-
Total Effect	37.305806	-	-	-

Mediation Effect

In order to quantify the mediation effect, we have calculated the direct effect, indirect effect and total effect (Table 4).

$$\boldsymbol{Total\ Effect = Direct\ Effect + Indirect\ Effect}$$

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Table 4. Calculating Total Effect

Effect	Value	Significance
Indirect Effect	16.9821	0.0077
Direct Effect	20.3236	0.0023
Total Effect	37.3057	

The Sobel test for the mediation produced a z-score (2.6630, P-value = 0.0077). Since the indirect effect is statistically significant a partial significant mediation is proved. Stating that health promotion partially mediates the impact of technological advancement on sustainable health outcomes of the firms which is significant with hypothesis H3. Various factors hinder the effectiveness of the impact of tech innovations on sustainable health solutions some of which can be insufficient training of health practitioners, inadequate investment, limited supply of essential medication, resource constraints, insufficient equipment and absence of oversight. All of these factors can be taken into consideration in the future to verify a complete mediation effect (Ahmed *et al.*, 2024). The proportion of mediation implies that 45.5% ({16.9821/37.3057} *100) of the total effect of technological advances on ESG performance is due to sustainable health promotion. We have also conducted a Leave-One-Out-Sensitivity-Analysis to verify if the mediation analysis is robust concerning the exclusion of individual companies (Figure 1). The results stated that the mediation effect is statistically significant in 4 out of 5 companies. If we take the confidence interval at 10%, we can say that all the companies show a statistically significant mediation effect.

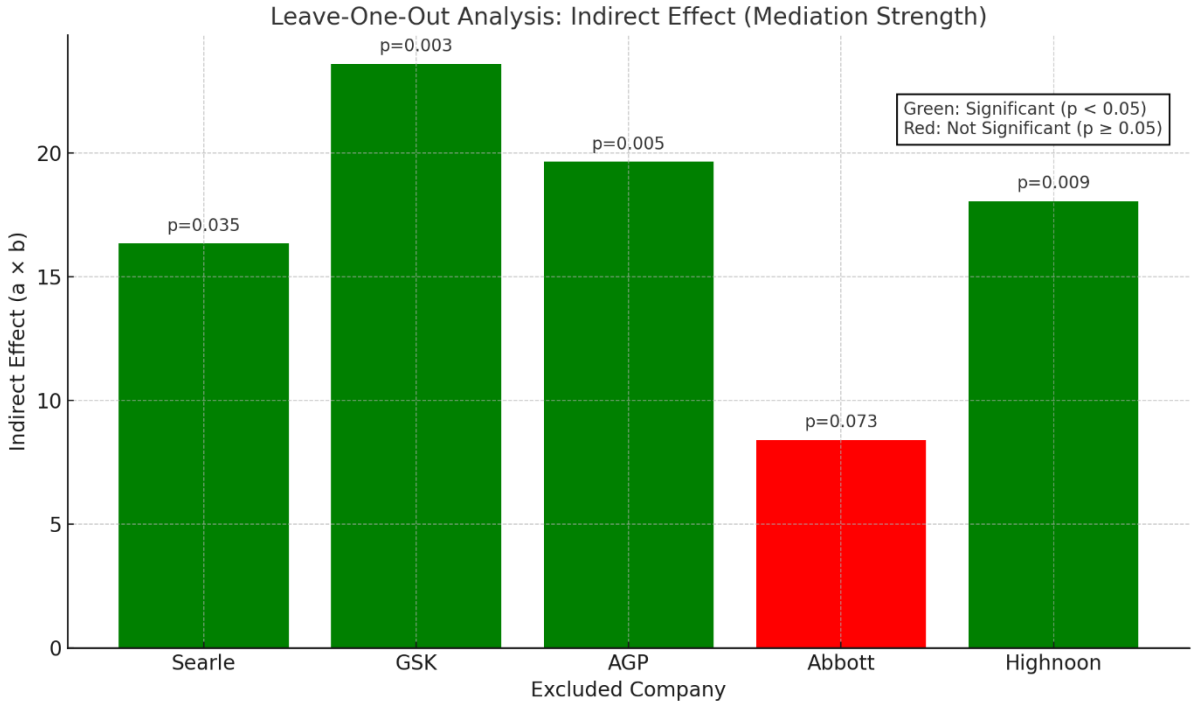

Figure 1. Leave-One-Out-Sensitivity-Analysis.

These results are in line with the prior literature that states that digital technological innovation can improve sustainable health solutions by enhancing human capital and internal controls

(Feng & Nie, 2024). Healthcare firms can implement employee wellness programs, personalized healthcare regimes, AIDS awareness and prevention Drives and track health metrics by leveraging digital platforms. This can result in an enhanced social responsibility leading to a better sustainable outcome. Firms that implement AI monitoring systems, mhealth applications, machine learning in predictive analysis, Electronic Health Records (EHRs), virtual health, surgical robotics, patient interaction through AI-driven chatbots, Automated Drug Dispensing Systems, smart wearables and pacemakers have the potential to contribute to towards environmental sustainability and healthcare accessibility. Firms implementing corporate health risk management, compliance with ESG and sustainability reporting standards, workplace health and safety guidelines, pandemic regulations, HIPAA & GDPR (Data Security) compliance, ethical AI considerations and board-level commitment to health enhance corporate governance leading towards an overall augmented sustainable healthcare system (Sapanakis *et al.*, 2016).

Conclusion

This study analytically scrutinizes the impact of technological advancement on the adoption of sustainable health solutions while health promotion serves as a mediating variable. The findings of the study imply that technological advancement has a significant positive impact on both sustainable health solutions and health promotion. The results from the panel regression using W-G bootstrap depict a strong model fit and demonstrate robustness. The results show that 45.5% of the total effect is mediated through health promotion. These findings are in line with the previous literature stating that healthcare efficiency, equity and sustainability can be achieved through digital health platforms, telemedicine, mobile health applications and AI-driven diagnostics. The study emphasizes that the firms that embed health promotion initiatives into their strategic implementation tend to have enhanced sustainable outcomes, and strengthened corporate and governance responsibility. Hence, technological advancement not only expedites healthcare accessibility and patient outcomes it also accords to broader sustainability goals. This can lead to a more effervescent and amenable healthcare ecosystem. The results of the study posit significant theoretical and practical implications. For healthcare providers and practitioners, this study highlights the importance of health promotion initiatives to boost the impact of tech advances to ameliorate sustainability metrics. Policymakers should prioritize tech investment in order to foster inclusivity and equity in healthcare delivery. The study is a contribution to the growing literature that links technological innovations with sustainable outcomes in the health sector, offering a paradigm that bridges organizational practices with broad-ranging Sustainable Development Goals (SDGs). Despite the robustness of the results, this study has a limitation in that the sample is only restricted to five healthcare firms for the year 2019-2023 which hinders the overall generalizability. Further studies could expand the scope by considering more firms across different countries. Moreover, future research could also explore the impact of certain moderating variables for instance firm size, structure of ownership, and firm age to investigate differential impacts. Lastly, there is an urgent need to develop a standardized framework for the estimation of the sustainability of health solutions across the healthcare domain, ensuring their ethics, effectiveness and accessibility.

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IJBB
International Journal of Biotechnology and Biomedicine
Vol. 1 No4; December 2024 https://doi.org/10.31674/ijbb.2024.v01i04.005

Appendix A

Category	Key Components	Examples in Hospitals
Technological Advances (Independent Variable)	Digital Health & Telemedicine	- Remote consultations via telemedicine platforms - AI-powered diagnostic chatbots - Mobile health apps for patient monitoring
	Electronic Health Records (EHRs)	- Cloud-based integrated patient records - AI-driven data analytics for patient history - Interoperability between hospital departments
	Medical Robotics & Automation	- AI-assisted robotic surgeries - Automated drug dispensing systems - Robotic rehabilitation devices
	Smart Hospitals & IoT	- Smart beds with real-time patient monitoring - IoT-enabled medical equipment tracking - Automated temperature and air quality control
	Advanced Medical Imaging	- AI-driven MRI/CT scan analysis - Real-time image enhancement for diagnostics - Remote radiology consultations
	3D Printing & Personalized Medicine	- Customized prosthetics and implants - 3D-printed surgical models - Bioprinting for regenerative medicine
	Big Data & Predictive Analytics	- AI for early disease prediction - Predictive models for hospital resource allocation - Real-time epidemiological tracking
Health Promotion (Mediating Variable)	Build Healthy Public Policy	- Compliance with universal healthcare policies - Hospital waste management and sustainability policies - Affordable treatment initiatives for vulnerable populations
	Create Supportive Environments	- Energy-efficient hospital buildings - Green spaces and stress-free environments for patients - Wellness programs for hospital staff
	Strengthen Community Action	- Free medical camps for underserved communities - Public health awareness campaigns - Collaboration with NGOs for disease prevention programs
	Develop Personal Skills	- Health literacy workshops for patients - Training programs on digital health for healthcare workers - Chronic disease management education
	Reorient Health Services	- Transition to preventive care models - AI-assisted diagnostics for early disease detection - Culturally sensitive healthcare programs

IJBB
International Journal of Biotechnology and Biomedicine
Vol. 1 No4; December 2024 https://doi.org/10.31674/ijbb.2024.v01i04.005

Sustainable Health Solutions (Dependent Variable)	Environmental Sustainability	- Solar-powered hospital infrastructure - Eco-friendly medical waste disposal - Reducing carbon footprint through telemedicine
	Financial Sustainability	- AI-based cost optimization for hospital operations - Public-private partnerships to enhance healthcare affordability - Efficient hospital resource management using predictive analytics
	Social Sustainability	- Digital health platforms improving healthcare accessibility - Ethical AI decision-making for equitable treatment - Community-driven healthcare models