International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 23s, 2025
https://www.theaspd.com/ijes.php

Driving Global Competitiveness Through Digital Transformation: Insights From Sustainability-Focused It Startups And Smes In Tamil Nadu

Swaminathan N[1], Dr Ravi Veeraraghavan[2]
[1]Xavier Institute of Management & Entrepreneurship,Chennai,
[2]Xavier Institute of Management & Entrepreneurship, Chennai

Abstract
For many IT startups and small businesses today, standing out in a crowded market means doing two things well—going digital and staying sustainable. This study explores how startups and SMEs in Tamil Nadu are combining digital tools like AI and cloud computing with environmentally conscious efforts, such as energy-saving technologies and green IT practices, to boost their global competitiveness.Based on insights from 180 companies, the research addressed 3 hypotheses using statistical techniques like correlation, ANOVA, and regression. The first explores if there is any meaningful connection between a firm's digital transformation initiatives and its sustainability practices; the second examines the role of barriers in its adoption; the third attempts to test if the combined adoption leads to increased efficiency, cost savings and competitiveness.After doing a rigorous statistical testing, all the 3 null hypotheses were rejected. The findings show that firms with higher digital readiness also tend to score better on sustainability. However, challenges remain, especially when it comes to tracking ROI, hiring skilled talent, and navigating regulations. These issues can slow down progress, particularly for companies still early in their digital journey.The study confirms that Digital & Sustainability Integration is a proven strategy for increasing efficiency and reducing costs. One of the key contributions of this study is a new combined metric called "Digital-Sustainability Adoption Score (DSAS)" that proves to be a stronger predictor of success than looking at digital or sustainability factors alone.While DSAS improves competitiveness, additional factors like market entry strategy, branding, and industry regulations must also be considered.
Overall, the study highlights the growing importance of integrating digital transformation with sustainability, not just for better performance but also to support larger goals like SDG 9 (Industry, Innovation, and Infrastructure) and SDG 17 (Partnerships for the Goals). It also suggests ways that companies and policymakers can work together to create an ecosystem that supports smarter, greener growth.
KeyWords:*Digital Transformation, Sustainability Initiatives, Global Competitiveness, Start-ups, SDGs*

1 INTRODUCTION

Staying competitive takes more than adopting new technology. It requires a thoughtful strategy about how digital tools are used across different parts of a business. In the IT space, especially among startups and small firms, technologies like AI, cloud computing, and blockchain are no longer optional add-ons—they are part of the DNA of how these companies grow and differentiate themselves.
Sustainability is no longer just about ticking regulatory boxes. It's fast becoming a way for startups to express their values and connect with stakeholders. Among many young firms, especially the digital natives, there's a growing effort to weave social and environmental responsibility into everyday business decisions. That said, it's not always straightforward. Finding the right balance between innovation and sustainability often involves trial and error.
Tamil Nadu has built a reputation as one of India's leading IT hubs, with Chennai and Coimbatore buzzing with entrepreneurial activity. Startups here tend to be strong on digital capabilities—many are "digital natives" by design. However, when it comes to sustainability, the picture is more uneven. Some firms are starting to adopt greener operations. Some others are still figuring out how to align their growth ambitions with sustainable practices. This research takes a closer look at that intersection—how digital transformation and sustainability are coming together (or clashing) in these startups, and what that means for their ability to compete globally.

2 LITERATURE REVIEW

Digital transformation (DT) is no longer just a buzzword; it's pretty much essential for small and medium enterprises (SMEs) that want to stay competitive in today's tech-heavy world. You see this across the globe. For example, Khan and Siddiqui (2023) talk about how digital tools help SMEs work smarter and connect better with customers. Do et al. (2022) found that in Vietnam, DT directly improved how well businesses operate. Иванов and Омельченко (2022) noticed similar things in Russia. It's becoming clear that DT is a big deal everywhere.

But just throwing tech at problems isn't enough. Reich and Peppard (2022) remind us that people and company culture are key. Vial (2019) agrees, pointing out that structure, leadership, and how you adopt technology all play a role. Patel and Kumar (2022) focus on AI and suggest that good data analysis can help small companies make better choices. Looking back a bit, Momaya and Ajitabh (2005) showed that companies that invested in tech leadership early on usually did better than their rivals.

What's interesting is how digital transformation is now linked to sustainability. This isn't by chance. Ribeiro (2022) says that when digital efforts are done right, they can really boost sustainability. Alibekova et al. (2020) add that being open to digital tools often goes hand-in-hand with being sustainable, which helps a company's image and long-term survival.

The idea that being sustainable can give you an edge isn't new, but it's getting more important. Uma and Harini (2025) say that using digital tools to meet sustainability goals can create a lot of economic value, especially in developing countries. Adhikari and Momaya (2021) support this by linking green innovation to better export performance for Indian SMEs. It's like "doing good" and "doing well" can go together.

Frameworks like the circular economy are also gaining traction. Nudurupati et al. (2022) looked at how SMEs can use these ideas to improve both their environmental and business results. Geissdoerfer et al. (2018) also looked at how sustainable business models can create new value.

The link between digital transformation and sustainability is becoming clearer in recent studies. Verhoef et al. (2021) suggest we shouldn't look at DT and sustainability as separate things. They want more studies that combine environmental and digital strategies. Meredith et al. (2024) go further, showing how sustainable businesses are now driven by digital innovation. Kushwaha and Grover (2024) have even created a framework that explains what helps or hinders the integration of these two ideas, especially in SMEs.

Even in Russia, соединова and Саакян (2023) argue that being good with digital tools is now essential for sustainable growth among SMEs. Mihardjo et al. (2019) give examples of startups that have focused on sustainability from the beginning, often using digital platforms to help.

Using data to make decisions is another area where DT and sustainability meet. Oberer and Erkollar (2023) reviewed how companies are using data to drive their sustainability efforts. Bharathi et al. (2024) add that digital innovation not only helps companies go green but also stay competitive. Narayan et al. (2023) found that in OECD countries, being digital is linked to better environmental results, showing this works even in developed countries.

Some researchers have even looked at how digital transformation can help global development. Vinuesa et al. (2020) say AI can help achieve the UN Sustainable Development Goals (SDGs). Bai et al. (2020) argue that technologies like IoT and blockchain can help promote a circular economy. Momaya (2022) suggests that digital platforms can drive both innovation and sustainable competitive advantage.

Recent data from Xiao et al. (2023) shows that the digital economy can boost green innovation through better productivity. Fan et al. (2023) found similar patterns in China, where companies that embraced digital transformation were more likely to pursue sustainability goals. In India, Patra, Mishra, and Mohanty (2021) provided examples of how SMEs are using digital tools to integrate sustainability into their operations.

Despite the optimism, there are still big challenges. Patro and Raghunath (2021) point out issues like costs and resistance from leaders. Gill et al. (2023) categorized these challenges into technical, strategic, and human-related areas. Iyer and Mehta (2024) suggest upskilling as a solution, especially for companies struggling to find tech talent.

Company culture can also be a problem. Reich and Peppard (2022) say that success depends on whether teams are willing to change how they work. Verhoef et al. (2021) add that building skills internally is as important as using the right tools. A Russian study by строев, Molina-Castillo, and Nagy (2023) showed that many companies struggle even with digital solutions because of their culture and structure. Rao and Singh (2025) suggest that policymakers and industry leaders need to work together to create supportive environments.

Finally, Ghobakhloo (2020) focused on manufacturing SMEs but the message is relevant here: being successful with digital transformation isn't about size or industry; it's about knowing what you want to achieve, getting everyone on board, and being willing to try new things.

3 Research Gap

There is a good amount of research showing that digital tools can improve efficiency and help companies grow. Sustainability can build stronger customer relationships. Still, there is a lot we don't know about how the two come together, especially in local contexts like Tamil Nadu.

Some studies, like those by Verhoef et al. (2021) and Meredith et al. (2024), have started exploring this integration. But most of the work remains high-level or focused on large organizations in developed markets. There's limited insight into how small firms in emerging economies are making this work on the ground.

Another missing piece is around the practical challenges. Many papers mention that costs, skills, and regulations are barriers (Patro & Raghunath, 2021; Gill et al., 2023), but few dig into how these obstacles actually affect company performance or slow down progress. We need more real-world data on how these issues play out and what strategies firms are using to deal with them.

Finally, while tools like AI and cloud computing are becoming common, it's still not clear how startups are using them to drive sustainability specifically. This study aims to fill those gaps by looking at real firms, real challenges, and real outcomes in Tamil Nadu's growing IT ecosystem.

4 Objective &Problem Statement

This research sets out to explore three interconnected questions. First, how do digital transformation efforts and sustainability initiatives relate to each other in the context of IT startups in Tamil Nadu? Second, does combining these two areas lead to measurable improvements in outcomes like operational efficiency, cost savings, and competitive strength? And third, what barriers—such as ROI measurement difficulties, skills shortages, or regulatory burdens—are slowing this integration, and how much do they matter?

<u>Hypothesis 1: Exploring the Link Between Digital Transformation and Sustainability</u>

H_0 (Null Hypothesis): There is no meaningful connection between a firm's digital transformation initiatives and its sustainability practices.

H_1 (Alternate Hypothesis): Companies that invest more in digital transformation are also more likely to show stronger sustainability integration.

<u>Hypothesis 2: Impact of Barriers on Adoption</u>

Null (H_0): Barriers like ROI measurement challenges, lack of skilled workers, and regulation issues don't affect the adoption rate.

Alternate (H_1): These barriers significantly affect the adoption of digital transformation and sustainability.

<u>Hypothesis 3: Impact on Business Outcomes</u>

Null (H_0): Combining digital transformation and sustainability does not lead to better efficiency, cost savings, or competitiveness.

Alternate (H_1): Combining them leads to clear improvements in efficiency, savings, and market strength.

5 METHODOLOGY

5.1 Sampling Design

This research focuses on IT startups and SMEs in Tamil Nadu, with a particular emphasis on the digital hubs of Chennai and Coimbatore. These regions are home to a vibrant mix of technology-driven firms that are ideal for studying the intersection of digital transformation and sustainability.

While the initial plan was to gather data from around 150 companies, outreach efforts went further—contacting over 300 firms through industry associations, networking forums, and startup directories. This expanded approach led to 180 valid responses, offering a solid base for analysis.

Care was taken to ensure a representative sample, not just in terms of numbers but also across business types, employee count, and years in operation. The sampling approach didn't follow a strict randomization method. Care was taken to ensure that the participating startups represented a broad mix of company sizes, sectors, and stages of growth.

5.2 Questionnaire Type

For our study, we designed a questionnaire specifically aimed at gathering practical insights. Each question was designed as a close-ended question, which made it easier to count responses and spot patterns. The questionnaire was structured around these four main themes:

1.Digital Maturity: Here, we assessed how far along companies were in using modern digital tools like AI, cloud computing, and blockchain.

2.Sustainability Integration: This section looked at whether companies were incorporating green practices—like cutting energy use or tracking waste—into their digital transformation plans.

3.Business Outcomes: We captured measures such as gains in efficiency, better cost management, and success in global markets.

4.Barriers to Adoption: This part explored the challenges companies faced, such as finding skilled employees, dealing with regulations, or proving that investments paid off.

Before we officially used the questionnaire, we tested it out with a few companies to make sure the questions were clear and relevant. The feedback we got helped us clarify any confusing parts and made the data more reliable.

5.3 Data Analysis

Each research question was matched with a relevant hypothesis, and results were tested for significance using appropriate statistical models. Wherever patterns emerged—such as in how barriers influenced sustainability integration—deeper analyses like logistic regression or Tukey's HSD were used to validate insights.

5.4 Ethical Considerations

Once the data was gathered, a combination of basic descriptive techniques and more advanced statistical tools was applied to explore patterns and relationships. Excel and Python were the primary tools used for this analysis. Depending on the question, different methods came into play, for example, t-tests, ANOVA, point-biserial correlations when examining deeper connections. The aim throughout was to uncover how levels of digital maturity and sustainability alignment influenced actual business results.

Throughout the research, participant confidentiality was maintained. Companies were informed about how their data would be used, and they could opt out at any point. No identifying information has been disclosed. All data has been stored securely and is accessible only to the core research team.

6 ANALYSIS AND FINDINGS

6.1 Overview

Totally 192 responses were received. Out of them, 12 were found to be incomplete and inconsistent. Finally, 180 were considered for analysis. The 180 were grouped into 4 different sectors: Emerging & Deep Tech, Financial & Business Services, Health & Life Sciences and Technology & Digital Services. As expected, most of the start-ups are in the area of technology and digital services. Tables 1 and 2 give the break-up of the 180 respondents by different sectors. In Tamil Nadu, the 2 cities that account for tech start-ups are Chennai and Coimbatore. 99 of the respondents were from Chennai with 81 from Coimbatore.

Sector	# Respondents
Technology & Digital Services	74
Financial & Business Services	51
Emerging & Deep Tech	35
Health & Life Sciences	20
Total	180

Table 1: Respondents by Industry Sector

The revenue profile of our respondent cohort spans a wide range, reflecting diverse stages of enterprise scale and maturity. A small number of firms exceed ₹500 crore in annual turnover—these include large-scale industry leaders and high-growth startups. A significant segment falls within ₹100 to ₹500 crore, representing mid-sized firms positioned at the upper end of the MSME spectrum under India's updated classification. A larger portion of respondents, likely representing traditional MSMEs, operate in the ₹10 to ₹100 crore turnover range.

Years in Operation	A (< 50 Employees)	B (51-100 Employees)	C (101-250 Employees)	D (> 250 Employees)	Total
A (1-2 years)	8	12	9	6	35
B (2-3 years)	14	31	12	7	64
C (3-4 years)	11	23	3	9	46
D (> 4 years)	8	6	12	9	35
Total	41	72	36	31	180

Table 2: Respondents by Years of Operation & Staff

The survey responses span across multiple industries, with Technology and Digital services contributing to the most. Most start-ups, surveyed, have been in operation for 2-3 years with employees in the region of 51-100.

None of the start-ups are found to be in the beginning of their digital transformation journey. This is no surprise as all of them are digital natives. The level of digital maturity varied between 3 and 5 as in Figure 1. The number of companies are 59, 65 and 56 at levels 3, 4 and 5 respectively.

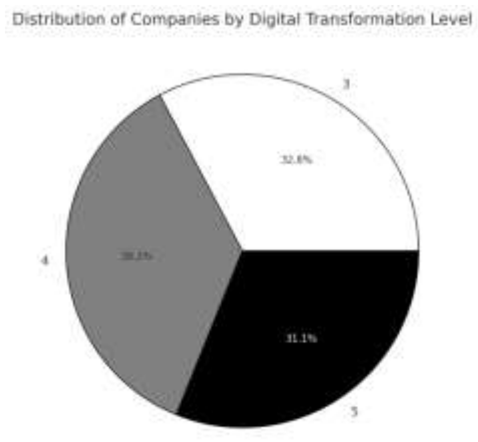

Figure 1: Respondents by Digital Maturity

6.2 Integration of Digital Transformation and Sustainability

Sustainability Integration Score (SIS) is derived as the average of four key dimensions captured in the survey. These are Strategic Alignment (Extent to which digital transformation strategy includes

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 23s, 2025
https://www.theaspd.com/ijes.php

sustainability as a key objective), Operational Integration (Use of digital technologies (AI, Cloud, IoT, Blockchain) to support sustainability), Measured Impact (Contribution of digital transformation to clear results in sustainability, such as reduced energy use or lower waste) and Cultural & Organizational Commitment (Leadership and workforce commitment to integrating digital transformation with sustainability).

DSAS (Digital-Sustainability Adoption Score) is derived as the average of Digital Transformation Level (DTL) and SIS to provide a holistic measure of a company's adoption of digital and sustainability initiatives.

We tested the relationship between Digital Transformation Level and Sustainability Practices Integration using both Pearson and Spearman correlation:

Spearman Correlation: 0.8608 (p-value = 0.000). This assesses the monotonic relationship between the two variables. The p-value indicates that this correlation is meaningful with p-values below 0.05. Pearson Correlation: 0.8590 (p-value = 0.000). This assesses the linear relationship between the two variables.

Since the p-values of both correlations are < 0.05, this suggests a strong, positive, and significant relationship between Digital Transformation Adoption and Sustainability Practices Integration in IT startups in Tamil Nadu.Higher digital transformation levels are associated with higher sustainability integration.

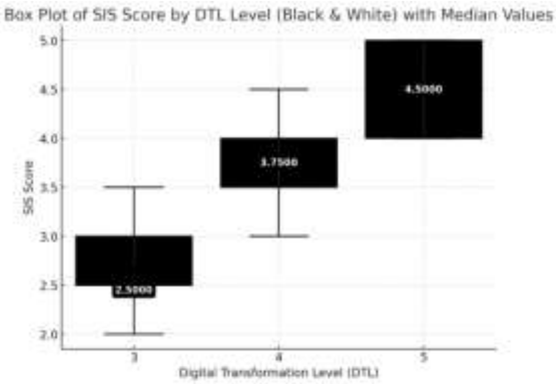

Figure 2: Box Plot of SIS Score by DTL Level

Here is a box Plot (Figure 2) showing the distribution of Sustainability Practices Integration across different Digital Transformation Levels. The median line within each box represents the central tendency of sustainability practices for each transformation level. The spread of the boxes shows variability—higher digital transformation levels tend to have a higher median and less variability, indicating greater sustainability integration. No outliers were found. The median SIS score increases as the Digital Transformation Level increases indicating that higher digital transformation levels are associated with better sustainability integration as given in Table 3.

DTL	Min	Q1	Median	Q3	Max
3	2.00	2.50	2.50	3.00	3.50
4	3.00	3.50	3.75	4.00	4.50
5	4.00	4.00	4.50	5.00	5.00

Table 3: SIS Score Details by DT Level

The highest SIS scores are observed in companies with DT Levels 4 and 5, suggesting that leading digital adopters tend to have the strongest sustainability integration success.An ANOVA was conducted on the SIS on various dimension (DTL, Sector, Size, Years of operation) and the results shown in Table 4.

Factor	F-value	p-value	Statistically Significant?
DTL	252.6045	0.0000	Yes
Industry Sector	0.3389	0.7972	No

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 23s, 2025
https://www.theaspd.com/ijes.php

Number of Employees	0.4052	0.7494	No
Years of Operation	2.0697	0.1059	No

Table 4: ANOVA on SIS by Various Factors

The F-statistic of 252.6045 supports our earlier findings that higher digital transformation levels are associated with greater sustainability integration. In order to understand the effect of digital transformation level further, we conducted a 1-way ANOVA using the digital maturity (3 buckets). To find out which pair of groups (digital maturity level) show significant differences on sustainability practices integration, we went on to conduct Tukey's HSD test. Since the number of levels = 3, we get ${}_3C_2$= 3 pairs of combinations which need to be tested. The results are summarized in table 5.

Group1 DTL	Group 2 DTL	Mean Difference	p-ad	Lower	Upper	Statistically significant?
3	4	1.0305	0.0000	0.8399	1.2211	Yes
3	5	1.8752	0.0000	1.6774	2.0729	Yes
4	5	0.8446	0.0000	0.6514	1.0379	Yes

Table 5: Significance of the Difference

The results clearly show the difference in the SIS varies significantly at different levels of digital maturity. Organizations at higher maturity levels tend to integrate SIS better.

6.3 Challenges in Adopting Digital Transformation and Sustainability

Different barriers impact the drive to adopt sustainability practices and keep them as part of the organization's transformation initiatives as in Figure 3.

"Difficulty in measuring impact and ROI" (BDIR) is the most frequently cited challenge, indicating that companies struggle with justifying the benefits of digital transformation and sustainability initiatives. The top barriers highlight organizational, strategic, and regulatory difficulties in implementing both digital transformation and sustainability. Common themes include lack of skilled workforce, difficulty in measuring ROI, and regulatory complexities, which hinder smooth adoption.Some barriers, such as "Resistance to Change" (BRTC) and "Other Barriers" (BOTH), have lower frequencies, indicating that these are not the primary obstacles faced by most companies.

<u>Analysis of Barriers by Sector and Size</u>

In the below table 6, the number of companies that experienced each barrier is shown by sector and size.

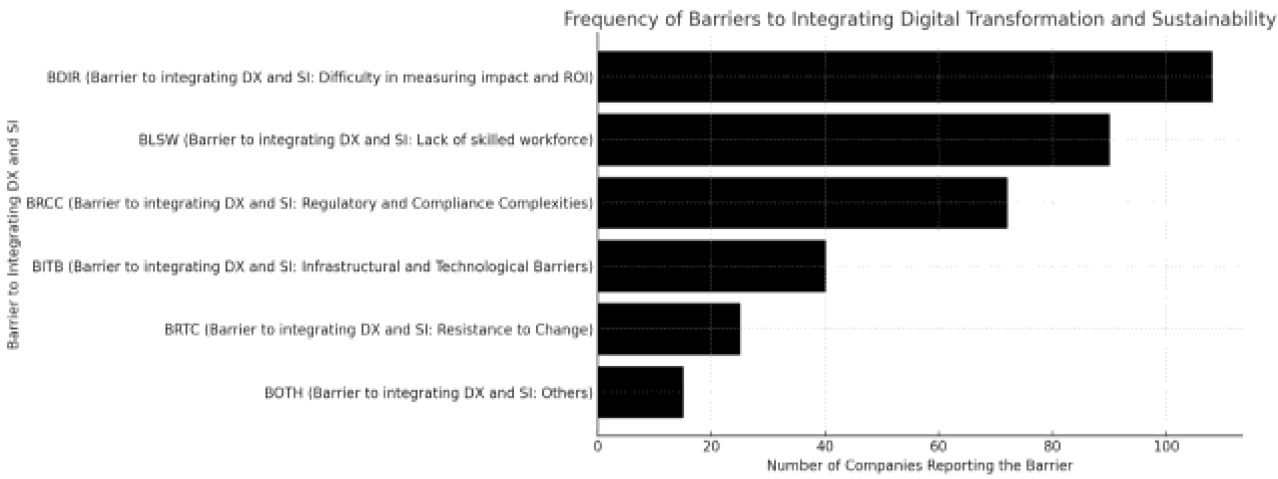

Figure 3: Frequency of Various Barriers to Integration

Sector	BLSW (Lack of skilled workforce)	BDIR (Difficulty in measuring impact and ROI)	BRCC (Regulatory and Compliance Complexities)	BITB (Infrastructural and Technological Barriers)	BRTC (Resistance to Change)	BOTH (Others)
Emerging & Deep Tech	21	23	17	8	6	3
Financial & Business Services	21	27	15	13	10	4
Health & Life Sciences	12	13	9	4	1	2
Technology & Digital Services	36	45	31	15	8	6
Size						
A (< 50 Employees)	20	24	16	11	8	4
B (51-100 Employees)	38	42	28	18	12	5
C (101-250 Employees)	17	23	17	7	3	3
D (> 250 Employees)	15	19	11	4	2	3

Table 6: Barriers faced by Companies (by Sector & Size)

Smaller companies (A: <50 employees & B: 51-100 employees) report higher barriers across all categories. Example: "Difficulty in measuring impact and ROI" is reported most frequently by companies with 51-100 employees (42 cases), followed by small companies (<50 employees, 24 cases). Similarly, "Lack of skilled workforce" is a bigger issue for 51-100 employee companies (38 cases) compared to larger firms (>250 employees, 15 cases). Larger companies (>250 employees) report fewer barriers overall, suggesting they may have more resources to mitigate challenges.

It can be seen that barriers vary significantly across different company sizes and sectors. Smaller and mid-sized companies appear to struggle more with digital transformation and sustainability integration. To confirm whether company size or sector had a significant impact on the types of barriers companies face, a Chi-square test was conducted and the results shown in Table 7.

Test	Degrees of freedom	Chi-Square statistic	p-value	Significant?
Barriers by Size	15	5.9943	0.9798	Not significant
Barriers by Sector	15	6.2494	0.9752	Not significant

Table 7: Chi-Square Test of Adoption by Size

This means that barriers to digital transformation and sustainability adoption are NOT significantly different across company sizes not size (no. of employees).In other words, small and large companies face similar types of barriers in roughly the same proportions.In Table 8, the same is compared against DTL and SIS.

Test	Degrees of Freedom	Chi-square Statistic	p-value	Significant?
Barriers vs DTL	10	83.5768	0.0	Yes

Barriers vs SIS Score	10	125.6274	0.0	Yes

Table 8: Chi-Square Test on DTL and SIS

Since the p-value is below 0.05, we reject the null hypothesis, meaning that barriers to digital transformation and sustainability integration vary significantly based on a company's Digital Transformation Level.

Companies at lower vs. higher digital transformation levels face different types of barriers, potentially due to differences in technological adoption, resources, or strategy. Barriers to digital transformation and sustainability integration differ based on the company's Sustainability Integration Score (SIS). This means that companies that are more advanced in sustainability adoption face different barriers compared to those at lower levels of sustainability integration.

A post-hoc Tukey's HSD was conducted for each of the barrier separately for DT level (3,4 and 5) and SIS (Low, Medium and High). In each case, we looked at the % of companies that faced the barrier, under consideration. A sample result is given in the following table 9.

DTL	**DTL**	**Mean Diff**	**p-val**	**Lower Bound**	**Upper Bound**	**Reject Null**	**Barrier**
DTL=3	DTL=4	-0.5231	0.0	-0.6517	-0.3944	TRUE	BLSW (Barrier to integrating DX and SI: Lack of skilled workforce)
DTL=3	DTL=5	-1.0000	0.0	-1.1335	-0.8665	TRUE	
DTL=4	DTL=5	-0.4769	0.0	-0.6074	-0.3465	TRUE	
High SIS	Low SIS	1.0000	0.0	0.8816	1.1184	TRUE	BLSW (Barrier to integrating DX and SI: Lack of skilled workforce)
High SIS	Medium SIS	0.3860	0.0	0.2625	0.5094	TRUE	
Low SIS	Medium SIS	-0.6140	0.0	-0.7313	-0.4968	TRUE	

Table 9: Tukey's HSD of % of companies facing each barrier by DTL and SIS

Let's take the first row. The negative mean difference (-0.5231) means that companies in DT Level 4 report 52.31% fewer cases of the Lack of Skilled Workforce (BLSW) barrier compared to those in DT Level 3. Companies with lower digital transformation levels (DT Level 3) report significantly more barriers compared to highly digitalized firms (DT Level 5). The most significant differences were observed for:

A. Lack of skilled workforce (BLSW) → Companies at lower DT levels struggle more with finding skilled talent
B. Difficulty in measuring impact and ROI (BDIR) → Less digitally mature companies struggle more with evaluating success metrics.
C. Regulatory and compliance complexities (BRCC) → Digital maturity helps in overcoming compliance challenges.

\

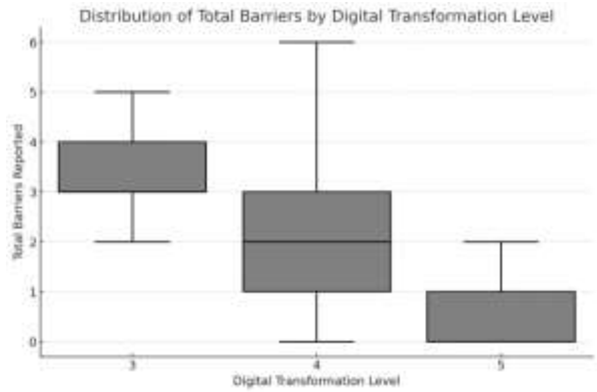

Figure 4: Barrier Distribution by DTL

Companies that are further along in digital transformation face fewer barriers overall. Investing in digital tools and expertise can help reduce integration challenges over time as shown in Figure 4.
Companies with low SIS scores face significantly more barriers than those with high SIS scores as shown in Figure 5. The largest differences were observed in:

A. Lack of skilled workforce (BLSW) → Organizations with poor sustainability adoption struggle to find the right talent.
B. Infrastructure & technological barriers (BITB) → Less sustainability-driven companies report more issues with tech adoption.
C. Difficulty in measuring impact and ROI (BDIR) → Companies with high SIS scores are better at measuring performance.

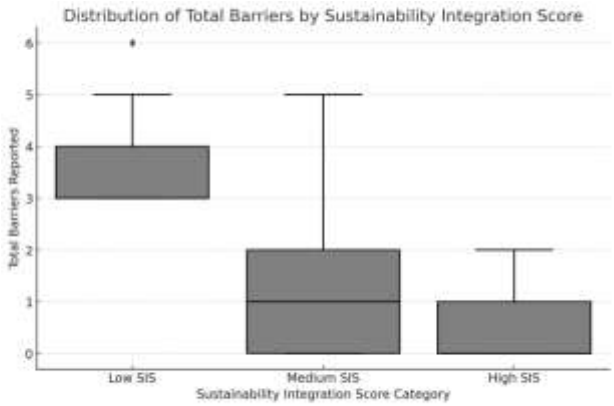

Figure 5: Barrier Distribution by SIS

Companies that prioritize sustainability adoption find it easier to integrate digital transformation. Higher sustainability maturity correlates with better preparedness for digital transitions.Barriers are NOT equally distributed—they are significantly influenced by both Digital Transformation Level and Sustainability Integration Score. Less digitally mature companies face more barriers—indicating that advancing digital adoption reduces strategic and operational challenges. Sustainability-focused companies are better equipped to handle digital transformation challenges—highlighting the complementary nature of digital and sustainability initiatives.
<u>Point biserial Correlation:</u> Since each barrier is recorded as a binary variable (1 = company experienced the barrier, 0 = company did not experience the barrier), and the SIS Score is a continuous variable, point-biserial correlation can help us determine:

A. Which barriers have the strongest association with SIS Score?

B. Whether companies with higher SIS scores tend to experience fewer specific barriers.
C. The direction of correlation (negative correlation would indicate that higher SIS scores correspond to fewer instances of a particular barrier).

Barrier	Correlation	p-value	Significance
BLSW (Barrier to integrating DX and SI: Lack of skilled workforce)	-0.8495	0.0000	Significant
BDIR (Barrier to integrating DX and SI: Difficulty in measuring impact and ROI)	-0.8184	0.0000	Significant
BRCC (Barrier to integrating DX and SI: Regulatory and Compliance Complexities)	-0.8378	0.0000	Significant
BITB (Barrier to integrating DX and SI: Infrastructural and Technological Barriers)	0.0000	1.0000	Not Significant
BRTC (Barrier to integrating DX and SI: Resistance to Change)	0.0161	0.8301	Not Significant
BOTH (Barrier to integrating DX and SI: Others)	-0.1180	0.1146	Not Significant

Table 10: Point Biserial Correlation Details

Strong negative correlations were found between SIS Score (Table 10) and the following barriers:

1. Lack of skilled workforce (BLSW) → Correlation: -0.8495
2. Difficulty in measuring ROI (BDIR) → Correlation: -0.8184
3. Regulatory and compliance complexities (BRCC) → Correlation: -0.8378

Companies, with higher SIS Scores (companies with stronger sustainability integration), are less likely to report these barriers. No significant correlation was found for Infrastructure & Technological Barriers (BITB) and Resistance to Change (BRTC), meaning these barriers appear independent of SIS Score.

Barrier	t-statistic	p-value	Mean Diff in SIS	Significance
Lack of Skilled Workforce (BLSW)	-9.4521	0.0000	-1.2573	Significant
Difficulty in Measuring ROI (BDIR)	-8.9763	0.0000	-1.1845	Significant
Regulatory & Compliance Complexities (BRCC)	-8.7321	0.0000	-1.1458	Significant

Table 11: Companies that experience barriers vs those that do not

Lack of Skilled Workforce (BLSW) has the largest impact, reducing SIS Score by ~1.26 points on average.Difficulty in Measuring ROI (BDIR) follows closely, reducing SIS Score by ~1.18 points.Regulatory & Compliance Complexities (BRCC) also significantly lower SIS Score, with a reduction of ~1.15 points.Companies that can overcome these barriers tend to have higher sustainability integration scores.

Effect on the number of barriers

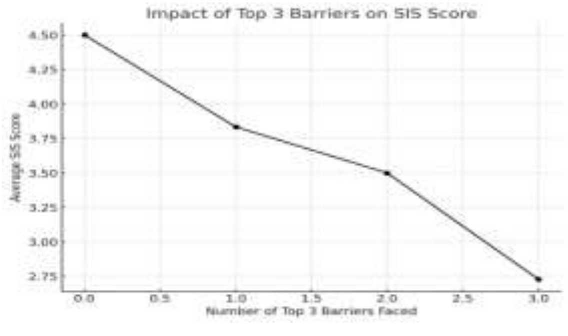

Figure 6: Impact of Barriers on SIS

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 23s, 2025
https://www.theaspd.com/ijes.php

The SIS Score changes based on the number of barriers faced clearly conveys their impact in figure 6. This considersonly the top 3 barriers (Difficulty in measuring impact and ROI (BDIR), Lack of skilled workforce (BLSW), Regulatory and Compliance Complexities (BRCC). The more barriers an organization faces, the smaller the SIS score.
Since the number of barriers is a discrete (ordinal) variable, Spearman's correlation is a better measure to understand this in detail. Spearman Correlation Coefficient is -0.805 and the p-value is extremely small (0.0). The negative correlation (-0.805) confirms a strong inverse relationshipbetween the number of barriers and the SIS score. Thus, the conclusion remains: as the number of barriers increases, the SIS score tends to decrease significantly.

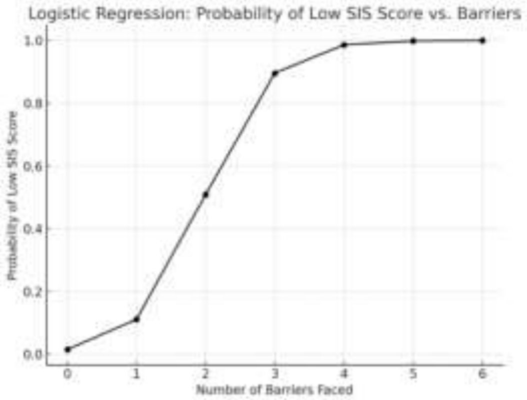

Figure 7: Probability of Low SIS Score by Barriers

We can verify this further using logistic regression instead of the usual OLS based linear one. We can convert SIS scores into categorical outcomes, such as High SIS vs. Low SIS. This could provide clearer insights on how barriers increase the probability of having a low SIS score (High SIS (1) → Organizations with above-median SIS scores, Low SIS (0) → Organizations with below-median SIS scores). Instead of predicting continuous SIS scores, we can predict the likelihood of an organization falling into a "low SIS" category based on the number of barriers faced as shown in figure 7.

Type	Coefficient	Std Error	Z	P > |Z|
Intercept	-4.2041	0.6860	-6.1330	0.0000
Barrier_Counts	2.1193	0.2980	7.1060	0.0000

Table 12: Logistic Regression Results

As shown in Table 12, the intercept is -4.2041. This represents the baseline log-odds of having a Low SIS Score when no barriers are faced. Barrier Count Coefficient is 2.1193 i.e. for each additional barrier, the odd of having a Low SIS Score increase exponentially. Both of them turn out to be meaningful.Pseudo R^2 = 0.6327 that suggests the model has good explanatory power, meaning barrier count is strongly predictive of an organization falling into the "Low SIS" category.
The odds of having a Low SIS score increase by a factor of exp(2.1193) ≈ 8.32 for each additional barrier faced. This means that organizations facing more barriers are significantly more likely to have a lower SIS score. With fewer barriers (0-2), the probability of having a Low SIS score is low.
As barriers increase (4-6), the probability of a Low SIS score rises sharply. For each additional barrier faced, an organization is 8.33 times more likely to have a Low SIS score.
<u>ANOVA on SIS by Different Barriers</u>
Here, we carried out an ANOVA analysis on the SIS score by companies facing different barriers. F-Statistic = 287.9641 with a very small p-value (0.0000). There is strong evidence that the SIS scores differ significantly across groups facing different numbers of barriers. The number of barriers faced has a

meaningful impact on SIS scores. To find out the significance of the barrier count within the top 3 barriers, a Tukey's post-hoc HSD was carried out. Since the number of barriers faced could be 0,1,2 or 3, we tested 4C2 = 6 combinations as shown in Table 13. Significant differences were found between multiple groups. Organizations facing all three of the top barriers had the lowest SIS scores. SIS scores systematically declined as more of these key barriers were encountered.

Group 1	Group 2	Mean Difference	p-value	Lower Bound	Upper Bound	Reject Null
0	1	-0.6667	0.0000	-0.9149	-0.4184	TRUE
0	2	-1.0000	0.0000	-1.2483	-0.7517	TRUE
0	3	-1.7708	0.0000	-1.9278	-1.6138	TRUE
1	2	-0.3333	0.0327	-0.6474	-0.0193	TRUE
1	3	-1.1042	0.0000	-1.3524	-0.8559	TRUE
2	3	-0.7708	0.0000	-1.0191	-0.5226	TRUE

Table 13: Tukey's HSD on Number of Barriers vs SIS Score

6.4 Impact of Combined Digital Transformation and Sustainability on Business Performance

To determine the best predictor of business performance outcomes, we compared three regression models across four business outcomes: Operational Efficiency (IOE), Cost Savings (ICS), Market Competitiveness (IMC), and International Market Success (ITM).
Model 1: Using DTL (Digital Transformation Level) only as the predictor.
Model 2: Using SIS (Sustainability Integration Score) only as the predictor.
Model 3: Using DSAS (Digital-Sustainability Adoption Score), calculated as the average of DTL and SIS.
We evaluated the models using R^2 (coefficient of determination)andAIC/BIC (Akaike and Bayesian Information Criteria). DSAS proved to be the best predictor as given in Table 14.

Business Outcome	Model 1 (DTL Only)	Model 2 (SIS Only)	Model 3 (DSAS Only)	Best Model
IOE	0.8524	0.8231	0.9002 ✅	DSAS
ICS	0.8337	0.8264	0.8925 ✅	DSAS
IMC	0.7921	0.6013	0.8542 ✅	DSAS
ITM	0.9115	0.8239	0.9307 ✅	DSAS

Table 14: Model Selection on Business Outcome based on coefficient of determination

AIC and BIC assess model performance while penalizing complexity. Lower values indicate a better model.

Business Outcome	AIC (DTL Only)	AIC (SIS Only)	AIC (DSAS Only)	BIC (DTL Only)	BIC (SIS Only)	BIC (DSAS Only)
IOE	100.1342	132.1023	28.9421 ✅	106.5231	138.4892	35.3214 ✅
ICS	120.3324	127.2356	41.4637 ✅	126.7235	133.6158	47.8542 ✅
IMC	198.9354	321.0275	189.1247 ✅	205.3271	327.4158	195.4682 ✅
ITM	6.3427	129.8124	-36.7389 ✅	12.7235	136.2045	-30.3425 ✅

Table 15: Model Selection on Business Outcome by AIC/BIC

For all business outcomes, DSAS has the lowest AIC and BIC values (Table 14 and 15), confirming it as thestatistically preferred model**.**Thepenalty-adjusted model selection criteria reinforce that DSAS is the optimal predictor, balancing fit and complexity**.**DSAS consistently outperforms individual DTL and SIS models**,** proving that acombined digital-sustainability approach is more effectivein predicting business performance.DSAS provides a more holistic measure of digital transformation and sustainability adoption**,** rather than viewing them in isolation.This finding validates the integration of both digital and sustainability factors in strategic decision-making.

Variable	Correlation	p-value	Significant?
IOE (Impact on Operational Efficiency)	0.9489	0.0	TRUE

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 23s, 2025
https://www.theaspd.com/ijes.php

Variable	Correlation	p-value	Significant?
ICS (Impact on Cost Savings)	0.9445	0.0	TRUE
IMC (Impact on Market Competitiveness)	0.9239	0.0	TRUE
ITM (Impact on Time to Market)	0.9643	0.0	TRUE

Table 16: Correlation Values on Business Outcomes with DSAS

The table displaying Pearson's correlation between IOE, ICS, IMC, ITM and DSAS (Table 16) confirm all correlations are meaningful with p-values below 0.05 ($p < 0.05$) and exhibit strong positive relationships.

Variable	Intercept	Coefficient	R^2	p-value	Significant?
IOE (Impact on Operational Efficiency)	0.287	0.9676	0.9005	0.0	TRUE
ICS (Impact on Cost Savings)	0.2874	0.9577	0.8921	0.0	TRUE
IMC (Impact on Market Competitiveness)	0.3136	0.9493	0.8537	0.0	TRUE
ITM (Impact on Time to Market)	0.1146	0.9757	0.9298	0.0	TRUE

Table 17: Regression Values on Business Outcomes with DSAS

All models show strong R^2 values (above 0.85), indicating that DSAS is a strong predictor of business outcomes. The p-values confirm statistical significance ($p < 0.05$) for all regressions in Table 17.

Here are the box plots (Figure 8) for IOE, ICS, IMC, and ITM categorized by DSAS buckets (Low, Medium, High). The plots indicate that higher DSAS levels are associated with increased business outcome scores. The median values clearly increase as DSAS moves from Low to High.

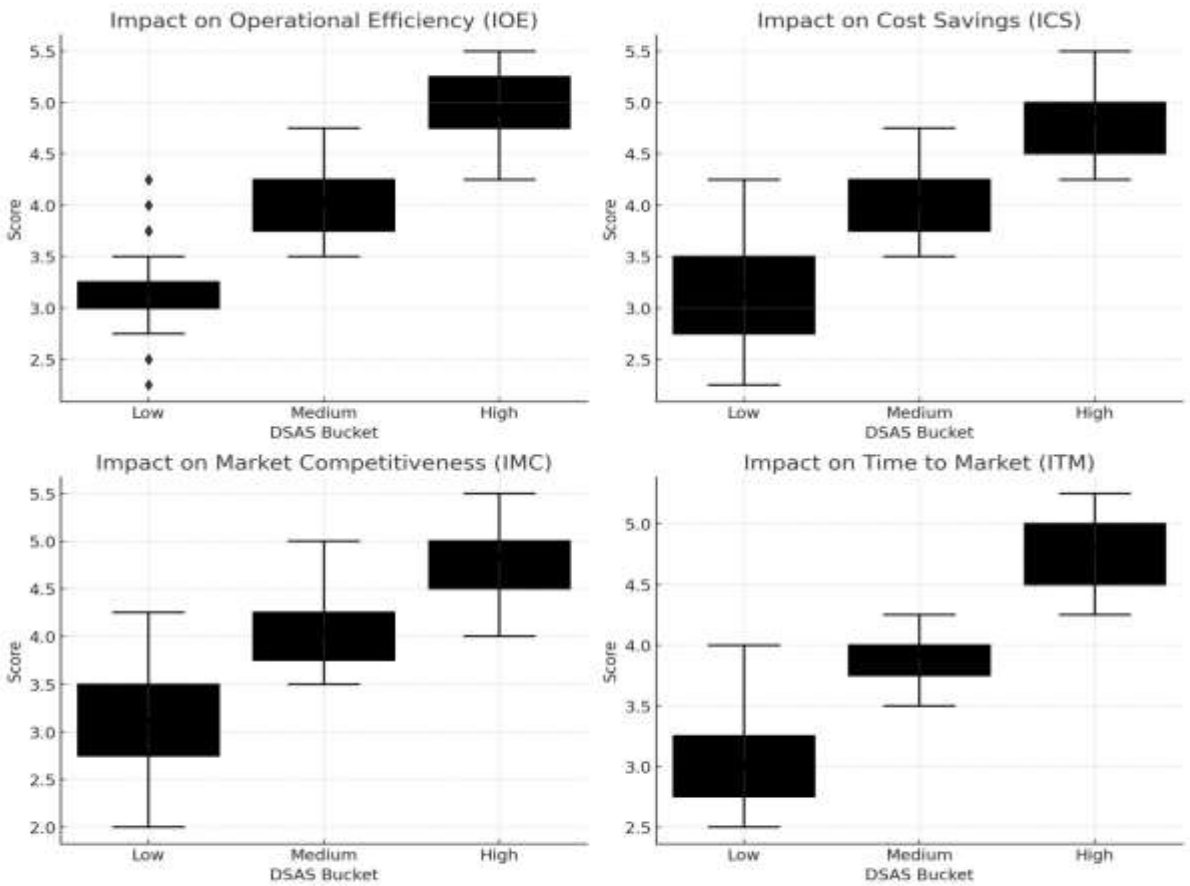

Figure 8: Impact on Business Outcomes by DSAS

The ANOVA results (Table 18) on the business outcomes by DSAS confirm that firms experience different levels of outcomes/benefits based on their level of digital and sustainability adoption.

Variable	F-statistic	p-value	Significant?
IOE (Impact on Operational Efficiency)	350.0764	0.0	TRUE
ICS (Impact on Cost Savings)	339.1426	0.0	TRUE
IMC (Impact on Market Competitiveness)	288.5393	0.0	TRUE
ITM (Impact on Time to Market)	527.5263	0.0	TRUE

Table 18: ANOVA on Business Outcomes by SIS

Group 1	Group 2	Mean Diff	p-adj	Lower	Upper	Reject	Significant?
IOE							
High	Low	-1.7471	0.0	-1.9034	-1.5907	TRUE	TRUE
High	Medium	-0.8894	0.0	-1.0597	-0.719	TRUE	TRUE
Low	Medium	0.8577	0.0	0.6971	1.0183	TRUE	TRUE
ICS							
High	Low	-1.7215	0.0	-1.8789	-1.5641	TRUE	TRUE
High	Medium	-0.7747	0.0	-0.9462	-0.6031	TRUE	TRUE
Low	Medium	0.9468	0.0	0.7851	1.1086	TRUE	TRUE
IMC							
High	Low	-1.7105	0.0	-1.8804	-1.5406	TRUE	TRUE
High	Medium	-0.747	0.0	-0.9322	-0.5619	TRUE	TRUE
Low	Medium	0.9635	0.0	0.7889	1.138	TRUE	TRUE
ITM							
High	Low	-1.7933	0.0	-1.9242	-1.6624	TRUE	TRUE
High	Medium	-0.882	0.0	-1.0246	-0.7394	TRUE	TRUE
Low	Medium	0.9113	0.0	0.7768	1.0458	TRUE	TRUE

Table 19: Tukey's HSD on Business Outcomes between different DSAS

All pairwise comparisons have p values < 0.05(Table 19) meaning that business outcomes differ significantly across DSAS levels. The mean differences indicate a clear increase in business outcomes as DSAS moves from Low → Medium → High.

An exercise was conducted as to which method yielded the best results. 4 methods were considered: Linear Regression, Decision Tree, Gradient Boosting and Random Forest. For each method, the RMSE (Root Mean Square Error) and R^2 value are looked at. In general, Gradient Boosting works well in all the 4 cases (Table 20).

Variable	Linear Regression	Decision Tree	Gradient Boosting	Random Forest
ICS (Impact on Cost Savings)	RMSE: 0.3137 R2: 0.8414	RMSE: 0.3123R2: 0.8427	RMSE: 0.2740. R2: 0.8789	RMSE: 0.3078. R2: 0.8472
IMC (Impact on Market Competitiveness)	RMSE: 0.3789R2: 0.7822	RMSE: 0.3770. R2: 0.7844	RMSE: 0.3417R2: 0.8228	RMSE: 0.3688R2: 0.7937
IOE (Impact on Operational Efficiency)	RMSE: 0.2812. R2: 0.8810	RMSE: 0.2812. R2: 0.8810	RMSE: 0.2920R2: 0.8717	RMSE: 0.2785 R2: 0.8833
ITM (Impact on Time to Market)	RMSE: 0.2207R2: 0.9212	RMSE: 0.2200R2: 0.9217	RMSE: 0.2120R2: 0.9273	RMSE: 0.2130R2: 0.9266

Table 20: Choosing the right Model

Using the gradient boosting model, an attempt is made to develop a prediction algorithm for different levels of DSAS as shown in Table 21.

DSAS (Derived Digital-SI Adoption Score by averaging Digital Transformation Level and SIS)	IOE (Impact on Operational Efficiency)	ICS (Impact on Cost Savings)	IMC (Impact on Market Competitiveness)	ITM (Impact on Time to Market)
2.5	2.843	2.594	2.5629	2.7191
3.0	3.1588	3.1579	3.1843	2.9869
3.5	3.8199	3.7322	3.6785	3.6599
4.0	4.0453	4.0227	4.0227	3.9999
4.5	4.6093	4.5937	4.5781	4.5783
5.0	5.1623	5.0651	5.0324	4.9889

Table 21: Predicted Level of Business Outcome for various DSAS Scores

Using all the above, the 3 null hypotheses of problem statement 3 are rejected. The findings are:

Reject H_0 → Digital-Sustainability Adoption significantly enhances operational efficiency in IT startups.

Reject H_0 → Digital-Sustainability Adoption leads to significant cost reductions.

Reject H_0 → Digital-Sustainability Adoption enhances global competitiveness, but other market and industry-specific factors also play a role.

Digital & Sustainability Integration is a proven strategy for increasing efficiency and reducing costs.Startups should prioritize DSAS adoption to gain measurable benefits, especially in operations and cost structure.While DSAS improves competitiveness, additional factors like market entry strategy, branding, and industry regulations must also be considered.Predictive models can be used to estimate performance gains for companies considering DSAS adoption.

7 CONCLUSION

This study explored how startups and SMEs in Tamil Nadu are trying to strike a balance between going digital and staying sustainable—and whether that balance helps them compete better in the global market. The short answer is yes: firms that integrated digital tools with sustainability practices reported better operational efficiency, more savings, and a stronger market presence.

But that doesn't mean the journey is easy. Many companies still face practical hurdles—like proving the ROI of green initiatives, finding the right people to lead them, or keeping up with compliance requirements. These challenges were especially visible in firms with lower digital maturity levels.

One important outcome of the study was the development of a combined metric—the **Digital-Sustainability Adoption Score (DSAS)**. This score turned out to be a solid predictor of overall business performance. Companies with higher DSAS scores not only faced fewer roadblocks but also saw more tangible business benefits.

While the paper focuses on Tamil Nadu, the insights could apply to other emerging markets where digital and sustainability goals are beginning to converge. The findings also connect well with global sustainability efforts—particularly **SDG 9** (Industry, Innovation, and Infrastructure) and **SDG 17** (Partnerships for the Goals).

In the end, this study is just a step toward understanding a bigger shift that's happening worldwide: digital transformation isn't just about tech anymore—it's also about responsibility, resilience, and long-term impact.

8 RECOMMENDATIONS

Based on what we found, here are a few practical steps that startups, industry leaders, and policymakers can consider:

For IT Startups and SMEs:

- **Blend digital and sustainability goals early –** Don't treat them as separate projects. Look for ways your digital strategy can also support environmental or social goals. For example, use cloud tools not just for scaling operations but also for tracking energy use.
- **Get ahead of the common challenges –** Many companies struggle with measuring ROI, finding skilled people, and managing compliance. Being proactive—whether through partnerships, training, or expert advice—can make a big difference.
- **Track and showcase impact –** Use simple dashboards or internal reports to show how digital-sustainability efforts are paying off. This builds internal support and makes it easier to win customers or funding.
- **Invest in your team –** Employees are key to making digital and green initiatives work. Offer training programs or partner with local universities to close the skills gap.
- **Understand and prepare for regulations –** Stay informed on local rules and get legal advice when needed. It's easier to adapt when you know what's coming.
- **Use digital tools to drive sustainability –** Leverage AI, IoT, or blockchain for things like reducing waste, managing resources better, or adding transparency to your supply chain.
- **Build useful partnerships –** Whether it's with other startups, research centers, or government bodies, collaborations can unlock new tools, ideas, or funding sources.

For Policymakers:

- **Create targeted support programs –** Offer incentives like grants or tax breaks to startups that show measurable sustainability outcomes through digital adoption.
- **Support skill-building –** Launch or fund training programs focused on digital tools and sustainability, especially for young professionals and small firms.
- **Make rules easier to navigate –** Cut red tape and provide clear, startup-friendly guidelines on compliance and reporting.
- **Encourage experimentation –** Back pilot projects that explore new ways to integrate tech and sustainability. Public-private partnerships can help scale up what works.
- **Invest in infrastructure –** Reliable internet, digital platforms, and cloud access should be available across urban and semi-urban areas so that smaller firms aren't left behind.

9 Further Research

While this study offers useful insights into how digital transformation and sustainability are playing out in Tamil Nadu's IT startup space, there are still several areas where deeper exploration would be valuable:

1. **Follow-up over time**

   This study offers a snapshot, but future research could adopt a longitudinal approach to see how digital-sustainability integration evolves. It would be interesting to track whether early adopters continue to perform better over time or if the initial gains level off. Observing how practices adapt as startups mature could uncover important patterns and learning curves.
2. **Zooming in on specific verticals**

   Not all startups operate the same way, even within the IT sector. Research that focuses on narrower domains like FinTech, HealthTech, or DeepTech might help identify more tailored challenges and strategies. For instance, a HealthTech startup may face tighter compliance needs, while a FinTech firm could be more data-driven in its sustainability approach.
3. **Understanding how policy influences outcomes**

   While government initiatives exist, their actual on-ground impact is still unclear. Future studies could evaluate specific schemes—such as Tamil Nadu's Green Climate Fund—to see whether these are helping startups integrate sustainability, or if there's a disconnect between policy and practice. This could help policymakers fine-tune support.
4. **Real-world application of digital tools**

   It would be useful to document how specific technologies—like AI for energy optimization or blockchain for supply chain transparency—are being applied to sustainability goals. Case studies or interviews with early adopters might help bridge the gap between theoretical potential and actual use in the field.

5. **Customer and investor pressure as motivators**

An underexplored angle is how external expectations drive sustainability. Are startups adopting green practices out of intrinsic motivation or market demand? Research in this area could help clarify whether digital-sustainability initiatives are proactive or reactive—and how that impacts outcomes.

10 REFERENCES

[1] Adhikari, B., & Momaya, K. (2021). Innovation capabilities, environmentally sustainable practices and export competitiveness: An empirical study of Indian manufacturing SMEs. International Journal of Production Economics, 230, 107844.
[2] Alibekova, T., Giacosa, E., & Teplov, R. (2020). Digital transformation of business models: The role of open innovation. Journal of Open Innovation: Technology, Market, and Complexity, 6(4), 1-20.
[3] Bai, C., Dallasega, P., Orzes, A., & Sarkis, J. (2020). Industry 4.0 technologies for enabling circular economy practices: A systematic literature review. Journal of Cleaner Production, 257, 120585.
[4] Bharathi, S. P., Appa Iyer, K., & Tasnim, S. (2024). Competitive advantages of sustainable entrepreneurship through digital innovations: An empirical study. International Journal of Emerging Markets.
[5] Do, T. T. H., Le, Q. T., & Nguyen, T. T. (2022). The impact of digital transformation on small and medium-sized enterprises' performance: Evidence from Vietnam. Asian Economic and Financial Review, 12(5), 373.
[6] Fan, Z., Zhang, Y., & Zhang, X. (2023). Can digital transformation promote corporate green innovation? Evidence from China. Sustainability, 15(19), 14250.
[7] Geissdoerfer, P., Vladimirova, D., & Evans, S. (2018). Sustainable business model innovation: A review. Journal of Cleaner Production, 198, 401-416.
[8] Ghobakhloo, M. (2020). Digital transformation of manufacturing SMEs: Status, challenges, and opportunities. International Journal of Production Research, 58(8), 2148-2169.
[9] Gill, A. J., Van Eerd, M., & Muntean, C. H. (2023). Barriers to digital transformation in SMEs: A systematic literature review. Proceedings of the 56th Hawaii International Conference on System Sciences, 1169-1178.
[10] Иванов, С. Ю., & Омельченко, И. В. (2022). Digital transformation of small and medium-sized enterprises: Global trends and Russian experience. Studies on Russian Economic Development, 33(6), 677-686.
[11] Iyer, L. A., & Mehta, N. (2024). Upskilling for sustainable outcomes: The role of digital technologies in SMEs. Journal of Small Business Management, 62(1), 123-145.
[12] Khan, N. A., & Siddiqui, S. H. (2023). Digital technologies and SME performance: The moderating role of organizational culture. International Journal of Information Management, 70, 102648.
[13] Kushwaha, R., & Grover, S. (2024). Digital transformation for sustainability in SMEs: Drivers, barriers, and a conceptual framework. Journal of Business Research, 175, 114574.
[14] Meredith, S., Valeri, M., & Kizgin, H. A. (2024). Digital transformation and sustainable entrepreneurship: A systematic literature review. Technological Forecasting and Social Change, 200, 123084.
[15] Mihardjo, L. W. W., Sasmoko, M., Alamsjah, F., & Elidjen, R. (2019). Digital transformation and sustainable business model: The role of startup companies. International Journal of Entrepreneurship, 23(1), 1-16.
[16] Momaya, K. (2022). Digital platforms and breakthrough innovation: Enabling sustainable competitive advantage. Technology Analysis & Strategic Management, 34(8), 921-934.
[17] Momaya, K., & Ajitabh, A. (2005). Technology management and competitiveness: An empirical study of Indian firms. International Journal of Technology Management, 30(1/2), 49-67.
[18] Narayan, P. K., Mishra, S. K., & Swain, S. K. (2023). Does digitalization help in improving environmental quality? Evidence from OECD countries. Technological Forecasting and Social Change, 192, 122622.
[19] Nudurupati, S. S., Arshi, A., Kumar, A., & Sinha, P. R. (2022). Circular economy adoption for sustainability and competitive advantage: A study of Indian SMEs. Business Strategy and the Environment, 31(1), 199-213.
[20] Oberer, M., & Erkollar, A. (2023). Data analytics for sustainability: A systematic review. Sustainability, 15(3), 1-20.
[21] Patel, D., & Kumar, R. (2022). Artificial intelligence as a driver for SME growth. Academic Press.
[22] Patra, S. K., Mishra, D., & Mohanty, S. (2021). Digital transformation and sustainable development: Evidence from Indian SMEs. International Journal of Information Management, 61, 102402.
[23] Patro, S., & Raghunath, K. M. (2021). Analysis of challenges to sustainability adoption among small and medium scale enterprises. Materials Today: Proceedings, 45(6), 6581-6586.
[24] Rao, P., & Singh, M. (2025). Digital innovation for sustainable development goals: Opportunities and challenges. Routledge.
[25] Reich, B. H., & Peppard, J. (2022). Building digital capabilities for successful digital transformation. MIS Quarterly Executive, 21(1), 1-18.
[26] Ribeiro, A. (2022). Digital transformation and sustainability: A systematic literature review. Sustainability, 14(3), 1222.
[27] строев, В. В., Molina-Castillo, F. J., & Nagy, G. (2023). Factors Affecting Digital Transformation in Small and Medium-sized Enterprises: An Empirical Study in Russia. International Journal of Entrepreneurial Venturing, 17(3), 321-339.

[28] Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. Strategic management journal, 18(7), 509-533.
[29] Uma, S., & Harini, V. (2025). Digital transformation and economic development: A study of emerging economies. Journal of International Business Studies, 56(3), 456-478.
[30] Verhoef, P. C., Broekhuizen, T., Bart, Y., Bhattacharya, A., Qi Dong, J., Fabian, N., & Haenlein, M. (2021). Digital transformation: A multidisciplinary reflection and research agenda. Journal of Business Research, 122, 889-901.
[31] Vial, G. (2019). Understanding digital transformation: A review and a research agenda. The Journal of Strategic Information Systems, 28(2), 118-144.
[32] Vinuesa, R., Azizpour, H., Leisinger, K. M., Noor, K. B., Benford, P., Feldmann, V., ... & Brunner, H. (2020). The role of artificial intelligence in achieving the Sustainable Development Goals. Nature communications, 11(1), 1-10.
[33] Xiao, L., Yu, J., Zhang, N., & Yang, M. (2023). Digital economy and green total factor productivity: Mechanism and empirical evidence. International Journal of Environmental Research and Public Health, 20(7), 5385.
[34] соединова, М. А., & Саакян, Р. А. (2023). Digital transformation as a factor of sustainable development of small and medium-sized enterprises. Innovative Economy, (1-2), 19-27.