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The Impact of Intellectual Capital on Sustainability Analytics Adoption in Manufacturing Companies

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Abstract
This study examines the impact of intellectual capital on the adoption of sustainability analytics in manufacturing companies. As organizations increasingly face pressure to enhance environmental, social, and governance (ESG) performance, sustainability analytics has emerged as a strategic tool to guide decision-making and improve operational efficiency. The research adopts a quantitative methodology, collecting data from managers and specialists in manufacturing firms through structured questionnaires. Intellectual capital is analyzed through its three main components: human capital, structural capital, and relational capital, assessing how each contributes to the effective integration of sustainability analytics. The findings reveal a significant and positive relationship between intellectual capital and the adoption of sustainability analytics, with human capital exerting the most substantial influence. The study concludes that leveraging intellectual capital is essential for driving data-informed sustainability strategies in the manufacturing sector. Recommendations are provided for enhancing knowledge-sharing systems and investing in employee capabilities to foster sustainable innovation.

Keywords: Intellectual Capital, Sustainability Analytics, Manufacturing Companies, Human Capital, Structural Capital, Relational Capital, ESG, Innovation

1 Introduction

With the onset of digitalization and growing environmental awareness, manufacturing companies are coming under mounting pressure to embrace sustainability in business. This has triggered the evolution of sustainability analytics, a data-driven approach that allows organizations to quantify, track, and improve their environmental, social, and economic performance (Ojokoh et al., 2020). Sustainability analytics is one of the most visible agenda tools used by organizations in addressing global sustainability agendas, regulative pressures, and stakeholder expectations (Vale et al., 2022). However, its effective implementation, to a very large extent, hinges on an organization's intellectual capital (IC)—a highly valued intangible asset made up of human know-how, systemized structural knowledge, and interdependent networks. Despite intellectual capital being firmly anchored as a generator of innovation and competitiveness, there is less studied application in harnessing its function to enable sustainability analytics among manufacturing firms (Alvino & Di Vaio, 2019).

Intellectual capital is the enabler for empowering the potential of an organization in leveraging data-driven sustainability practices. Human capital, being employees' competences, technical skills, and solution-finding capabilities, play an important role towards enabling the optimal utilization of sustainability analytics tools (Yusoff et al., 2019). Workers' expertise in data interpretation, artificial intelligence, and big data analytics gives companies the ability to extract meaningful information to be used in making smart decisions regarding sustainability initiatives (Delmas et al., 2013). Similarly, structural capital, such as databases, IT infrastructure, and internal processes, provides the foundation on which sustainability analytics can be embedded in business decision-making systems (Malik et al., 2020). Without highly advanced data systems and analytical capabilities within an organization, it will not be able to exploit the full potential of sustainability analytics (Delmas et al., 2013). Further, relational capital, i.e., a company's stakeholder, customer, regulator, and industry peer relationship, promotes collaboration and helps in adherence to sustainability practices (Alvino & Di Vaio, 2019). Through the enablement of relational capital, firms can align sustainability practices with industry practices and expectations (Jabbour & Jabbour, 2016).

Sustainability concerns are industry-specific. Companies must reconcile economic development and environmental sustainability in such a way that their activities not only please regulators but also generate profits. Transparency through sustainability reporting is being demanded by governments, investors, and consumers alike, which is fueling the need for robust data analytics capabilities (Vale et al., 2022). Strategic leveraging of intellectual capital holds the promise of enhancing the sustainability performance of organizations and attaining sustainable long-term competitive success (Alvino & Di Vaio, 2019). The majority of the organizations, nonetheless, are faced with the challenge of low stakeholder sustainability-oriented intellectual capital awareness, thereby inhibiting its diffusion and utilization (Alvino & Di Vaio, 2019). Such challenges raise significant questions as to how firms can leverage their knowledge assets to render sustainability analytics effective and enhance their sustainability performance.

This study aims to fill this gap in knowledge by examining the role of intellectual capital in the adoption of sustainability analytics by manufacturing firms. More precisely, this research aims to identify how human, structural, and relational capital facilitate effective use of data-based sustainability metrics (Yusliza et al., 2020). Through examining synergetic interdependencies between these IC dimensions, this research will make valuable contributions to business managers, policymakers, and academics (Ojokoh et al., 2020). Through understanding how IC can be connected with sustainability analytics, companies can develop means of enhancing their environmental performance, resource productivity, and sustainability reporting (Jabbour & Jabbour, 2016).

2 Literature Review

Human Capital and Sustainability Analytics Adoption

Human capital is the most important driver of effective implementation of sustainability analytics by manufacturing firms. Different studies highlight the importance of the awareness, innovation, and sensitivity of employees towards the environment in bridging gaps between sustainability objectives and quantifiable data-driven action. For instance, Malik et al. (2020) showed how green human resource management with the development of human capital makes the adoption of sustainability practices feasible. Those employees who have analytical skills, sustainability knowledge, and problem-solving skills are more likely to manage high-end analysis tools and draw insightful conclusions out of complex data (Yusoff et al., 2019).

Yusliza et al. (2020) confirmed this relationship by building a structural model that established the direct relationship of green intellectual capitals, one of which is human capital, and sustainable firm performance. Similarly, Iqbal et al. (2023) also outlined that human capital triggers green product innovation and process innovation, both of which are significantly dependent on the ability to read and implement sustainability programs.

Another notable contribution is provided by Akmalia and Muharam (2024), who reasserted that although structural capital contributed the most to sustainable growth among Indonesian companies, human capital remained significant in underpinning knowledge-based sustainability strategies. Grant (1996) and Nonaka and Takeuchi (1995) are some of the theoretical authors presenting evidence for these findings, claiming that knowledge in individuals is the foundation of innovation and strategic change. Tonial et al. (2019) supplemented this by demonstrating that worker knowledge promotes data collection, reporting precision, and sustainability innovation when connected to organizational strategy.

Structural Capital and Sustainability Analytics Adoption

Structural capital in the form of internal processes, databases, IT infrastructure, and innovation habits is also critical in leveraging sustainability analytics within business functions. It facilitates the technical infrastructure needed to ensure production companies effectively receive, process, and examine the data for sustainability. Bontis et al. (2000) pointed out that information technologies and structurally ordered knowledge systems are facilitators to capitalize on data-driven strategies into sustainability strategy initiatives. Companies possessing greater structural capital are best equipped to exploit real-time sustainability dashboards, monitoring of resources by IoT, and analytics-based prediction tools.

Malik et al. (2020) set that structural elements such as green policies and eco-centric databases are key to guaranteeing the success of sustainability performance if they are incorporated into the business's digital transformation strategy. Ojokoh et al. (2020) also clarified that after manufacturing firms adopt big data and artificial intelligence platforms with robust structural designs, sustainability analytics implementation is more manageable and affordable.

Delmas et al. (2013) argued that strong structural capital enables firms to comply with environmental regulation through internal reporting and monitoring. In the same vein, Tonial et al. (2019) illustrated with their case study of a Brazilian company that digital infrastructure and knowledge repositories enable the institutionalization of sustainability practices.

Rashid et al. (2024) placed great importance on green supply chain management and analytics-driven decision-making supported by convergent IT infrastructure. Therefore, the success in implementing sustainability analytics entirely depends upon the structural capital maturity of a firm. In the lack of robust digital and procedural setup, sustainability programs tend to be under-leveraged and unstructured.

Relational Capital and Sustainability Analytics Adoption

Relational capital or a firm's external relations with external players like customers, suppliers, government agencies, and industry networks is central to the adoption of sustainability analytics. The relations create an enabling environment of mutual knowledge, co-innovation, and collective practices of sustainability. Past research supports the argument that relational capital is an enabler for the reception of sustainability norms and external knowledge into the firm and, in the end, the firm's ability to apply and digest data-driven sustainability tools improves.

For example, Zahoor and Gerged (2021) ensured to have a constructive effect of great relational capital upon the environmental performance of SMEs in emerging markets by incorporating the environmental knowledge along with communicating the stakeholders. Similarly, Yu et al. (2020) ensured that stakeholder engagement has immediate effects on strategic alignment and execution of sustainability analytics, especially when firms are considering responding to mutual sustainability expectations. Such interactions provide the potential for trust development and collaborative learning environments essential to advanced analytics tool adoption.

In addition, empirical evidence by Van Zyl (2023) determined that relational capital enables corporate reporting and disclosure, enabling real-time synchronizing of sustainability data with strategic goals. Relatively mature relational networks within corporates get more visibility of sustainability initiatives, regulatory requirements, and environmental agendas at an industry level. This enables customization and deployment of analytics-driven solutions at high velocity. Likewise, Jain and Jamal (2022) also centered on the aspect that green data-sharing culture results from long-term supply chain collaboration through traceability and sustainability adoption of analytics in supply chains.

Sustainability Analytics Adoption and Innovation Performance

Recent research has given clear indications of the association between the adoption of sustainability analytics and manufacturing firm innovation performance. Because sustainability analytics is based on big data, artificial intelligence, and digital technology, it allows innovative products, achieves process efficiency, and helps create green products. Rashid et al. (2024) contended that business companies leveraging analytics are able to better predict environmental trends and optimize operations, sparking ongoing innovation in supply chain management and product innovation. In a similar perspective, Ojokoh et al. (2020) indicated that the real-time monitoring of data by leveraging AI technologies enhances the adaptive potential of companies to environmental pressures, sparking innovative manufacturing solutions.

A number of empirical studies have confirmed that analytics enables the attainment of eco-innovation and differentiation of products. Awadallah and Elnady (2020) confirmed that sustainability analytics enables decision-making based on evidence, which leads to the optimal R&D activity and green product innovation design. Malik et al. (2020) also confirmed that a mix of digital analytics and human and structural capital maintains innovation. This was corroborated by Yusliza et al. (2020), whose study indicated that firms with data platforms to aid sustainability will likely embrace green processes and technology.

Sustainability Analytics Adoption and Competitive Advantage

Use of sustainability analytics (SA) in business strategy has emerged as a key driver to attain competitive advantage in manufacturing. Because sustainability has emerged as a necessity to enable building stakeholder trust and regulatory compliance, organizations leveraging advanced analytics tools derive strategic advantage through value-optimizing operations, increased transparency, and enabling green innovation. There is existing literature that justified the positive correlation of SA implementation with competitiveness positioning, where emphasis has been provided to how evidence-based best practices enable firms to react to environmental pressures and remain sensitive to global sustainability objectives (Rashid et al., 2024).

For instance, Rashid et al. (2024) remark that BDA and AI highly rely on competitive advantage via real-time decision-making and supporting green product innovation among producers. Similarly, Ojokoh et al. (2020) believe that AI technologies are greener with greater reliability in sustainability reports and hence discriminate against firms that compete in highly environmentally oriented markets.

Awadallah and Elnady (2020) also contribute that investment in analytics capability and digital infrastructure enhances the value of environmental monitoring and compliance and provides manufacturers with reputational advantage and access to environmentally sensitive markets. Vale et al. (2022) also attest that intellectual capital utilization with sustainability analytics promotes operational understanding and increases the adaptive capability of a firm operating in ever-changing regulatory environments.

Sustainability Analytics Adoption and Competitive Advantage

Sustainability analytics (SA) is a competitive corporate strategy for companies that want to be leaders in a changing, green economy business environment. By incorporating advanced data analysis in sustainability programs, companies are able to monitor environmental, social, and economic performance in real time, identify operating inefficiencies, and innovate on the edge. In business, where regulatory adherence, resource optimization, and environment upkeep are overriding concerns, the adoption of sustainability analytics is no longer a strategic choice but a competitive imperative.

There is literature that supports the sustenance of sustainability analytics adoption in enhancing competitive strength. Rashid et al. (2024) confirmed that the implementation of big data analytics by manufacturing firms and the utilization of artificial intelligence in their green supply chain attained high market competitiveness via operations effectiveness, cost reduction, and enhanced sustainability performance. Similarly, Ojokoh et al. (2020) observed that sustainability efforts that are data-based lead to greater stakeholder trust and better environmental disclosure that impact positively on customer loyalty and brand differentiation.

Awadallah and Elnady (2020) also argued further that sustainability analytics enables organizations to respond better to external regulatory pressure while enhancing in-house processes such as resource deployment and strategic management. This two-pronged effect—externally legitimacy, internally efficiency—makes SA an important asset to be used in long-term competitiveness. Moreover, Malik et al. (2020) instituted that firms that utilize green intellectual capital and data analytics can better align innovation strategies and environmental objectives, thus yielding long-term value and sustainability for competitive markets.

3 Methodology

Data Collection Method and Questionnaire Distribution

For the purpose of collecting data and information, two sources were adopted, namely:
First, secondary sources: The study relied on secondary sources with the aim of building a theoretical framework that includes the study variables through relevant Arabic and foreign references and books, in addition to bulletins, websites, books, magazines, research, and previous studies in a manner consistent with the study topic.
Second, primary sources: Primary sources were relied upon by preparing a special and validated questionnaire. It was distributed to the study sample to obtain data related to the study and its problem according to the five-point Likert scale. The questionnaire included all dimensions of the study, questions, and hypotheses of the study, and for the purpose of addressing the analytical aspects.

Descriptive Analysis

Human Capital (Independent Variable) Means ranged from 3.94 to 4.08, with a mean of 4.01 and a standard deviation of 0.84, indicating a strong perceived capability among employees regarding sustainability-related skills. The highest-rated item was "Knowledge sharing among employees enhances our sustainability efforts" (M = 4.08, SD = 0.90), reflecting the value of collaborative learning. The lowest mean (M = 3.94) was associated with technical skills in using big data and artificial intelligence, indicating potential room for skill development. Overall, human capital appears to be a strong asset within organizations when it comes to driving sustainability analytics. For more information, the following table shows the rest of the Descriptive Analysis.

Table 1: Descriptive statistics

Constructs	N	Min	Max	Mean	Std.Deviation
Human Capital (IV)					
1. Our employees have strong analytical and problem-solving skills relevant to sustainability	200	1.00	5.00	3.9900	.93502
2. Staff are trained to use data analytics tools for sustainability monitoring	200	1.00	5.00	3.9950	.92153
3. Employees possess adequate knowledge about sustainability goals and standards.	200	1.00	5.00	4.0000	.92427
4. We have a skilled workforce capable of using big data and AI in sustainability applications.	200	1.00	5.00	3.9450	.95211
5. Our organization invests in continuous learning related to sustainability analytics.	200	1.00	5.00	4.0700	.87689
6. Knowledge sharing among employees enhances our sustainability efforts.				4.0750	.90191
Average	200	1.00	5.00	4.0125	.84240
Structural Capital (IV)					
. Our organization has an integrated database system supporting sustainability reporting	200	1.00	5.00	3.9250	.78898
We use IT systems effectively to collect and analyze sustainability-related data	200	1.00	5.00	3.9600	.81345
Our internal procedures promote the use of data in environmental performance evaluation.	200	1.00	5.00	3.9200	.83492
4. We have a well-documented process for tracking sustainability KPIs.	200	1.00	5.00	3.9550	.85241
5. Our sustainability analytics tools are regularly updated to meet regulatory standards.	200	1.00	5.00	3.9150	.81307
6. Digital infrastructure in our organization facilitates effective sustainability practices.	200	1.00	5.00	3.5200	.91311
Average	200	1.00	5.00	3.8658	.74248
Relational Capital (IV)					
1. We collaborate with stakeholders (e.g., customers, suppliers) on sustainability initiatives.	200	1.00	5.00	3.5550	.88934
2. Our company shares environmental performance data with partners.	200	1.00	5.00	3.4300	.94847
3. We receive support from government bodies regarding sustainability policies.	200	1.00	5.00	3.5250	.91847
4. Our networks enhance our ability to adopt sustainability analytics.	200	1.00	5.00	3.5300	.89054
5. Partnerships contribute positively to our sustainability goals.	200	1.00	5.00	3.6050	.91277
6. Our stakeholders actively participate in our sustainability plans.	200	1.00	5.00	2.4050	.96208
Average	200	1.00	5.00	3.3417	.61089
Sustainability Analytics Adoption (DV)					
1. We have adopted analytics tools to track and report sustainability performance.	200	1.00	5.00	2.4200	.92622

2. Our decisions are based on data generated from sustainability analytics.	200	1.00	5.00	2.2300	.92269
3. We use real-time data analysis to reduce environmental impact.	200	1.00	5.00	2.5000	.96157
4. Sustainability analytics is integrated into our business strategy.	200	1.00	5.00	2.3700	1.01402
5. Big data and AI are used to identify sustainability-related risks and opportunities.	200	1.00	5.00	4.1200	.71284
6. Our analytics platform supports our sustainability reporting obligations.	200	1.00	5.00	4.1550	.72360
Average	200	1.00	5.00	2.9658	.59010
Innovation Performance (DV)					
1. Sustainability analytics has led to the development of innovative products or processes.	200	1.00	5.00	4.2000	.68729
2. We have introduced new eco-friendly products in recent years.	200	1.00	5.00	4.1900	.66036
3. Data-driven sustainability practices have improved operational efficiency.	200	1.00	5.00	4.3350	.70374
4. Our sustainability initiatives drive technological innovation.	200	1.00	5.00	3.8300	.85131
5. Analytics help us identify areas for green innovation.	200	1.00	5.00	3.7950	.86992
6. Our innovation performance has improved due to our sustainability focus.	200	1.00	5.00	3.8800	.86565
Average	200	1.00	5.00	4.0383	.58568
Competitive Advantage (DV)					
1. Sustainability analytics has strengthened our competitive position.	200	1.00	5.00	3.8350	.91760
2. We have achieved cost reductions through sustainability analytics.	200	1.00	5.00	3.7150	.89318
3. Our reputation has improved due to the use of sustainability analytics.	200	1.00	5.00	4.4500	.54680
4. Data-driven sustainability strategies help us outperform competitors.	200	1.00	5.00	4.4750	.55761
5. Sustainability practices give us a market advantage.	200	1.00	5.00	4.4400	.58146
6. Our analytics use aligns with customer demands and expectations.	200	1.00	5.00	4.4250	.57097
Average	200	1.00	5.00	4.2233	.40942

4 Data Analyses

Failure to fulfill the assumptions required for regression analysis negatively affects the results of hypothesis testing, as an incorrect correlation appears between the study variables. Accordingly, some of the tests required by regression analysis were conducted, as they required the fulfillment of three conditions: first, that the sample be chosen randomly, second, that the data follow a normal distribution, and third, that there be no autocorrelation problem between the independent variables.

The first condition was met when selecting the study sample, as a random sample was chosen. This was achieved when selecting the study sample, where a simple random sample was chosen to represent the study population. As for the second condition related to the normal distribution of the data, the sampling distribution approaches the normal distribution when the sample size is larger than (30) observations. To confirm this, the Smirnov test was used, which is considered one of the most widely used tests. The values in this test show that the data follows a normal distribution when they are greater than (0.05).

Table 2: normal distribution

	Sample Kolmogorov	p-value	Result
Human Capital	.861	.211	normal
Relational Capital	.923	.198	normal
Structural Capital	.953	.157	normal

The data follows a normal distribution for the study variables and their dimensions, as the statistical significance value of the test was greater than (5%) and not significant at the level of (0.05) for all study variables. Based on the above, we conclude that the study data follows a normal distribution.

The First Main Hypothesis

To test the first main hypothesis, simple linear regression analysis was performed.

The first main hypothesis of the study was as follows **"Human capital positively affects the adoption of sustainability analytics among manufacturing companies"**

Table 3: result of the First Main Hypothesis

Independent variable	"t" value	"t" sig	B	R	R2	"F" value	"F" sig
Human capital	14.119	.000	.492	.708	.502	199.346	.000

The table (3) shows that there is a statistically significant effect (Human capital) in (adoption of sustainability analytics where the correlation coefficient reached ((R=0.708), which indicates the existence of a statistically significant correlation between the independent variable Human capital in adoption of sustainability analytics. It has been shown that the value of the coefficient of determination (R2 = 0.502, which indicates that Human capital explained (50.2%) of the variance occurring in adoption of sustainability analytics, while the remainder is due to other variables that were not included in the model. The value of (F = 199.34) was at a confidence level equal to (sig = 000). This confirms the significance of the regression at a significance level of 0.05 > (α). It appears from the coefficients table that the value of (B) reached (.492) and that the value of (t) was (14.119) with a statistical significance of (0.000), which indicates the presence of a significant effect.

The second main hypothesis of the study was as follows **"Relational capital significantly affects facilitating the adoption of sustainability analytics among manufacturing companies."**

Table 4: result of the second Main Hypothesis

Independent variable	"t" value	"t" sig	B	R	R2	"F" value	"F" sig
Relational capital	.639	.409	.492	.659	.434	151.742	.000

The table 4 shows that there is a statistically significant effect (Relational capital) in (adoption of sustainability analytics where the correlation coefficient reached (R=0.639), which indicates the existence of a statistically significant correlation between the independent variable Relational capital in adoption of sustainability analytics. It has been shown that the value of the coefficient of determination (R2 = 0.409), which indicates that Relational capital explained (40.9%) of the variance occurring in adoption of sustainability analytics, while the remainder is due to other variables that were not included in the model. The value of (F = 151.742) was at a confidence level equal to (sig = 000). This confirms the significance of the regression at a significance level of 0.05 > (α).It appears from the coefficients table that the value of (B) reached (.492) and that the value of (t) was (12.318) with a statistical significance of (0.000), which indicates the presence of a significant effect.

The third main hypothesis of the study was as follows:**" Structural capital facilitates successful adoption of sustainability analytics among manufacturing organizations"**

Table 5 result of the third Main Hypothesis

Independent variable	"t" value	"t" sig	B	R	R2	"F" value	"F" sig
Structural capital	11.699	.000	.613	.659	.434	136.874	.000

The table 5 shows that there is a statistically significant effect (Structural capital) in (adoption of sustainability analytics where the correlation coefficient reached (R=0.659), which indicates the existence of a statistically significant correlation between the independent variable Structural capital in adoption of sustainability analytics. It has been shown that the value of the coefficient of determination (R2 = 0.464), which indicates that Structural capital explained (46.4%) of the variance occurring in adoption of sustainability analytics, while the remainder is due to other variables that were not included in the model. The value of (F = 136.874) was at a confidence level equal to (sig = 000). This confirms the significance of the regression at a significance level of 0.05 > (α). It appears from the coefficients table that the value of (B) reached (.613) and that the value of (t) was (11.699) with a statistical significance of (0.000), which indicates the presence of a significant effect.

The fourth main hypothesis of the study was as follows:**" Sustainability analytics adoption positively affects organizational performance, i.e., innovation performance and competitive advantage"**

Table 6: result of the fourth Main Hypothesis

dependent variable	"t" value	"t" sig	B	R	R2	"F" value	"F" sig
organizational performance	-4.755	.000	.318	.320	.102	22.605	.000
competitive advantage"	8.554	.000	0.718	.519	.270	73.172	.000

The table 6 shows that there is a statistically significant effect (Sustainability analytics adoption) in (organizational performance)where the correlation coefficient reached (R=0.32), which indicates the existence of a statistically significant correlation between the independent variable Sustainability analytics adoption in adoption of organizational performance. It has been shown that the value of the coefficient of determination (R2 = 0.102), which indicates that adoption of sustainability analytics explained (10.2%) of the variance occurring in organizational performance, while the remainder is due to other variables that were not included in the model. The value of (F = 22.602) was at a confidence level equal to (sig = 000). This confirms the significance of the regression at a significance level of 0.05 > (α). It appears from the coefficients table that the value of (B) reached (.318) and that the value of (t) was (-4.755) with a statistical significance of (0.000), which indicates the presence of a significant effect.

5 Discussion

The findings strongly support a significant and positive influence of human capital on the adoption of sustainability analytics. The correlation coefficient (R = 0.708) indicates a high degree of association, while the coefficient of determination (R^2 = 0.502) reveals that 50.2% of the variance in the adoption of sustainability analytics can be explained by human capital alone. The standardized coefficient (B = 0.492) and the high t-value (14.119, p = 0.000) confirm this strong predictive relationship.

The analysis also demonstrates a statistically significant impact of relational capital on the adoption of sustainability analytics, with a correlation coefficient of R = 0.639 and R^2 = 0.409. This means that 40.9% of the variance in adoption is attributable to relational capital. The regression coefficient (B = 0.492), supported by a t-value of 12.318 (p = 0.000), further confirms the positive association.

The study confirms that structural capital has a significant and positive effect on the adoption of sustainability analytics. The results show a correlation coefficient of R = 0.659 and $R^2 = 0.464$, indicating that 46.4% of the variation in adoption can be explained by structural capital. The regression coefficient (B = 0.613) and the corresponding t-value (11.699, p = 0.000) validate this relationship.

The study found a statistically significant but relatively modest relationship between the adoption of sustainability analytics and innovation performance, with R = 0.320 and $R^2 = 0.102$. This indicates that 10.2% of the variance in innovation performance is explained by sustainability analytics adoption. The regression coefficient (B = 0.318), along with a negative t-value (-4.755, p = 0.000), still affirms the presence of a meaningful connection.

Finally, the results clearly demonstrate that the adoption of sustainability analytics significantly enhances competitive advantage, with a correlation coefficient of R = 0.519 and $R^2 = 0.270$. This means that 27% of the variability in competitive advantage is accounted for by sustainability analytics adoption. The regression coefficient (B = 0.718) and t-value (8.554, p = 0.000) strongly support this conclusion.

This finding indicates that manufacturing firms using sustainability analytics are more likely to achieve differentiation, efficiency, and responsiveness in their markets. By leveraging analytics to inform strategic decisions, optimize operations, and reduce environmental impact, these firms can gain a substantial edge over competitors.

The comparative analysis reveals strong consistency between this study's results and a substantial body of existing research. The study reinforces the significance of intellectual capital dimensions in facilitating sustainability initiatives and highlights the mediating role of sustainability analytics in enhancing organizational performance. While there are some contextual variations, particularly regarding the influence of human capital, the general alignment with previous findings confirms the robustness and relevance of the study's conclusions for both academic and practical applications.

6 Research Implications

Theoretical Implications

This study makes a significant theoretical contribution by integrating the Intellectual Capital framework with the concept of Sustainability Analytics within the context of manufacturing firms. The results reinforce and extend the Resource-Based Theory (RBT) by demonstrating that intangible assets—such as human, relational, and structural capital—are critical enablers of sustainability analytics adoption. Furthermore, the study confirms that the adoption of such analytics leads to improved innovation performance and competitive advantage, suggesting that intellectual capital is not only a resource but also a strategic capability that enhances organizational sustainability.

Practical Implications

From a managerial perspective, the study emphasizes the need for investment in human capital development, particularly through training programs focused on data literacy, environmental awareness, and analytics tools. Firms should prioritize recruiting and retaining talent with the technical and strategic skills needed to implement sustainability analytics effectively. The findings also suggest that building and maintaining strong external relationships—with suppliers, customers, and stakeholders—is essential for supporting sustainability objectives. Organizations should engage in strategic partnerships and knowledge-sharing initiatives to enhance relational capital.

7 Conclusion

This study aimed to investigate the role of intellectual capital—specifically human, relational, and structural capital—in driving the adoption of sustainability analytics within manufacturing companies, and to assess how such adoption influences innovation performance and competitive advantage.

The results, derived from quantitative analysis using linear regression, revealed strong empirical support for the proposed model. All three components of intellectual capital were found to have a significant and positive impact on the adoption of sustainability analytics. Among them, human capital emerged as the most influential, followed by structural and relational capital. These findings highlight the critical importance of investing in knowledge, systems, and external relationships to support sustainable digital transformation.

In addition, the study demonstrated that sustainability analytics adoption contributes positively to organizational outcomes—namely innovation performance and competitive advantage. Although the relationship with innovation was moderate, the impact on competitive advantage was stronger, suggesting that firms leveraging analytics to support sustainability are better positioned to enhance their market performance and strategic positioning.

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