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Sustainable Development Adoption in the High-Tech Sector: A Focus on Ecosystem Players and Their Influence

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Abstract: In an era marked by increasing concerns about environmental sustainability, the telecommunications industry faces a pressing need to examine its commitment to sustainable development practices. Therefore, this study investigated the drivers and constraints influencing the adoption of such practices within the industry, with particular emphasis on the roles and interactions of ecosystem players. The research employed structural equation modeling (SEM) in AMOS to test the hypotheses and multilayer perceptron (MLP), which is an artificial neural network model, to assess the importance of each variable in the context of sustainable development adoption (SDA). This study analyzed data obtained from a diverse sample of telecommunications professionals, including telecom operators, device manufacturers, technology providers, and content and service providers. The findings reveal that stakeholder expectations held the highest normalized importance, suggesting their paramount influence in driving sustainable practices within the industry. Competitive advantage emerged as the second most significant factor, contributing to the adoption of sustainable strategies by companies. Conversely, cost and ROI concerns presented a constraint that potentially hindered SDA. This research contributes to the comprehensive understanding of sustainable development in the high-tech sector, aiding industry practitioners and policymakers in fostering a more sustainable future for the telecommunications industry. The implications derived from the sensitivity analysis provide valuable insights into prioritizing efforts and resources to enhance sustainable development adoption in the telecommunications sector.

Keywords: sustainable development adoption; telecommunications ecosystem players; drivers; constraints; structural equation modeling (SEM); multilayer perceptron (MLP)

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1. Introduction

The high-tech industry, which is characterized by constant innovation and digital transformation, has revolutionized the global economy. In tandem, the telecommunications sector, as an integral part of high-tech, has transformed the way people communicate,

conduct business, and access information. These industries collectively shape modern society, but their rapid expansion has also raised environmental concerns, requiring a sustainable approach to development. The telecommunications industry, as a high-tech industry, stands as a vital pillar of the global economy, facilitating rapid communication and connectivity across the world. Its role in shaping modern society cannot be understated, with telecommunications enabling seamless interactions and driving innovation across various sectors. As the high-tech landscape continues to evolve, marked by constant technological advancements and breakthroughs, the industry's potential for positive change becomes increasingly pronounced. Amidst this backdrop, environmental sustainability and sustainable development practices have gained immense prominence as crucial imperatives across industries. The telecommunications industry has witnessed unparalleled growth in recent years, driven by cutting-edge technologies and digital innovations. From the proliferation of high-speed internet to the advent of 5G networks and the Internet of things (IoT), the sector has continuously transformed the way people communicate, conduct business, and access information. This ever-changing landscape not only presents vast opportunities but also poses unique challenges concerning environmental impact and resource consumption.

The telecommunications industry faces a myriad of environmental challenges, including escalating energy consumption, electronic waste generation, and the environmental impact of network infrastructures. The telecommunications industry solutions for overcoming these challenges are green product design, energy efficiency, renewable energy usage, waste reduction and recycling, circular economy, carbon footprint reduction, supply chain sustainability, lifecycle assessment [1], environmental certifications, environmental awareness and training, and collaboration and advocacy. However, to implement these solutions, they need to first adopt sustainable developments. Twagirayezu et al. [2] highlighted that the lack of sustainability considerations among telecom companies is concerning given the sector's escalating e-waste volumes. They argue that more research is imperative to understand the drivers and barriers for telecom operators to implement comprehensive sustainability strategies. Khan et al. [3] also note that despite the environmental benefits, telecom firms have been slow to transition to renewable energy, with most still relying heavily on fossil fuels. They conclude that studies are crucial for promoting renewable energy adoption across the telecom industry. Furthermore, Silva et al. [4] found that e-waste from obsolete telecom gear and consumer electronics will grow massively in the coming years, yet recycling rates remain low. Additional research is called for to devise solutions that enable global e-waste reduction and management. De Felice et al. [5] also highlighted that most telecom companies lack a systematic approach to evaluate and minimize the environmental impacts of their extensive network infrastructure. More work is needed to develop sustainability best practices and frameworks suitable for the telecom sector. Moreover, Micholia et al. [6] asserted that further studies are urgently required to provide practical guidance to telecom operators on integrating sustainability considerations into their core operations and decision-making processes. Prevailing research affirms that facilitating the adoption of sustainable development in the telecommunications industry is an increasingly important but understudied issue that warrants further scholarly investigation through empirical studies. This underscores the rationale and significance of the proposed research aims to address this gap. Therefore, the primary aim of this study was to investigate the drivers and constraints of sustainable development adoption in the telecommunications industry through an ecosystem approach. By analyzing key factors that influence sustainability practices, this research sought to shed light on effective strategies for promoting environmental stewardship within the high-tech sector. This study holds significant implications for the telecommunications industry and the broader landscape of sustainable business practices. By identifying the key drivers and constraints of sustainable development adoption, industry stakeholders, policymakers, and environmental advocates can make informed decisions to foster a more environmentally conscious and socially responsible high-tech sector. Additionally, the findings of this research will contribute to

the growing body of knowledge in sustainable development, offering insights into how an ecosystem approach can facilitate sustainable practices in other industries as well. This study focused on selected high-tech companies within the telecommunications sector across different regions. Geographical and sector-specific boundaries were established to ensure coherence and relevance to the research objectives.

This article is structured into several sections to present a comprehensive analysis of sustainable development adoption in the telecommunications industry. The manuscript follows a logical flow, beginning with the Theoretical Framework section, which outlines the conceptual basis and ecosystem approach used in the study. The Methodology section details the research design, data collection methods, and analytical techniques. The Results section presents the findings of the study, while the Findings and Discussion section delves into the interpretation and implications of these results. Finally, the Conclusion section summarizes the key insights and highlights the study's broader contributions to the field of sustainable development in the telecommunications industry.

2. Theoretical Framework

2.1. Regulatory Pressures

Governments play a crucial role in promoting sustainability practices through regulations and policies that mandate or encourage responsible business conduct. In the telecommunications industry, key regulatory pressures include e-waste rules, energy efficiency standards, and sustainability reporting requirements.

A study by Masocha and Fatoki [7] on small and medium enterprises in South Africa found that coercive pressures, like environmental laws, had a significant impact on the adoption of sustainability practices across economic, environmental, and social dimensions. This shows that government regulations successfully pressure companies to improve sustainability. Similar findings were reported in research on the Indian automotive industry by Mathivathanan et al. [8]. Their analysis identified government regulations as one of the most influential drivers for implementing sustainable supply chain management. Mandates make industries more willing to adopt practices they may not pursue voluntarily. Jakhar et al. [9] also found that regulatory stakeholder pressure inhibits manufacturing firms in India from adopting an enduring sustainability focus, unlike in China, where regulations have a positive effect. This indicates the power of regulation to shape corporate strategy. Furthermore, Awan et al. [10] determined that stakeholder pressures, like those from the government, significantly influenced the adoption of sustainable supply chain practices and performance among Pakistani manufacturers. This emphasizes regulators' role in promoting responsibility. The literature provides considerable evidence that government regulations and policies act as coercive pressure on telecoms and other industries to adopt sustainable development practices. Mandatory requirements make social and environmental performance necessary rather than optional. Therefore, the first hypothesis that regulatory pressures drive sustainable development adoption in the telecommunications industry is written as follows:

H1: *Regulatory pressures constitute a factor driving sustainable development adoption (SDA) in the telecommunications industry.*

2.2. Stakeholder Expectations

Beyond government regulations, expectations and pressures from other stakeholder groups also influence telecom companies to adopt more sustainable practices. Key stakeholders include customers, investors, NGOs, and supply chain partners. A systematic review by Meixell and Luoma [11] found that stakeholder pressures on companies result in greater sustainability awareness, goal setting, and implementation of responsible practices. Different stakeholders have varying impacts on a range of environmental and social issues. This shows stakeholder activism compels action. Amran and Ooi [12] explain that pressure from stakeholders causes businesses to improve sustainability disclosures and governance to prove accountability. Engaging stakeholders helps telecoms to obtain feedback to meet

expectations. Jakhar et al. [9] determined that stakeholder pressures trigger manufacturing firms to adopt sustainable practices, though the response depends on the firm's capabilities. This still demonstrates stakeholder power. Bello-Pintado et al. [13] found that individual stakeholder groups have differential roles in driving the adoption of internal, external, and collaborative sustainability practices in manufacturing. Firms react selectively to each group's demands. Furthermore, Awan et al. [10] established a strong link between stakeholder pressures and the implementation of sustainable supply chain practices in Pakistani manufacturers. This enhanced sustainability performance. In summary, the evidence indicates that expectations and activism from customers, investors, NGOs, and other stakeholders pressure telecom companies to adopt sustainable development practices. Meeting stakeholder demands improves a company's reputation and accountability. Therefore, the second hypothesis was formulated as follows:

H2: *Stakeholder expectations constitute a factor driving sustainable development adoption (SDA) in the telecommunications industry.*

2.3. Resource Scarcity

The telecommunications industry faces rising resource costs and scarcity concerns that pressure companies to adopt more sustainable practices. Energy is a key area of focus, as network infrastructure consumes massive amounts of electricity. Zhang et al. [14] explained that telecom optical networks are energy intensive, creating an imperative to develop technologies that conserve power. This drives energy efficiency efforts. Ibhaze et al. [15] also highlighted the need for energy-efficient solutions in emerging wireless systems to avoid unnecessary power consumption. Choosing efficient technologies minimizes costs. Ahmed et al. [16] argued that energy efficiency and renewable energy adoption are crucial for telecoms to reduce expenses and environmental impacts. Transitioning to green power, like solar, reduces dependence on costly grid electricity. Beyond energy, Pargman and Wallsten [17] discussed how finite minerals, like copper, used in telecom networks are becoming scarcer. This makes material efficiency an important goal. Water scarcity is another concern motivating sustainable innovations. Hope et al. [18] showed how mobile technologies are expanding water access and payments in Africa, addressing scarcity. Data centers are a major electricity sink for telecoms. Warkozek et al. [19] and Koomey [20] demonstrated the massive power appetite and costs of servers and data centers. This creates economic incentives to improve efficiency. Rising energy, mineral, water, and land costs, coupled with resource constraints, pressure telecom companies to adopt sustainable practices that conserve resources, cut utility costs, and improve efficiency. The economic benefits of using resources more responsibly provide a sustainability driver. Therefore, the third hypothesis considered was as follows:

H3: *Resource scarcity and cost concerns constitute a factor driving sustainable development adoption in the telecommunications industry.*

2.4. Competitive Advantage

Beyond cost and resource pressures, adopting sustainable practices can also provide telecom companies with competitive advantages over rivals. Sustainability helps to attract customers, investors, and top talent while building a brand reputation. Bhandari et al. [21] found a concave relationship between sustained competitive advantage and ESG performance at the firm level. Embedding in ecology, society, and governance boosted competitive position. This shows sustainability's strategic value. Ahmadi-Gh and Bello-Pintado [22] determined that effectively implementing sustainability practices improves sustainability outcomes, which then enhances manufacturing firms' competitive advantage. This highlights the benefits of sustainability. Cantele and Zardini [23] established that sustainability practices lead to a competitive advantage for small businesses by increasing reputation, customer satisfaction, and employee commitment. Sustainable firms outperform peers. Rodriguez et al. [24] argued that sustainability fosters innovation and knowledge assets

that generate persistent competitive advantage. A dynamic, sustainable view of the firm shows how sustainability enables value creation. In the telecom industry, sustainability helps operators to stand out. For example, T-Mobile US' renewable energy purchases have earned recognition and positive PR. Its competitor AT&T has lagged in sustainability. This differential performance shapes brand perceptions. Studies across industries and firm sizes demonstrate that sustainability adoption enhances competitive positioning through reputation gains, customer and employee loyalty, innovation, and resilient operations. Therefore, the fourth hypothesis was designed as follows:

H4: *Competitive advantage is a factor driving sustainable development adoption (SDA) in the telecommunications industry.*

2.5. Innovation and Efficiency

Developing innovative technologies and finding efficiencies are key ways telecom companies can improve sustainability performance. Green innovations and optimized processes reduce environmental footprints and costs. Wu et al. [25] found that both formal regulations and informal stakeholder pressures positively influence companies to pursue green innovations for sustainability. This highlights innovation's role. Aftab et al. [26] established that green innovations fully mediate the link between environmental ethics and sustainable performance. Developing eco-friendly technologies and offerings is crucial. Huang et al. [27] determined that sustainable development practices promote digital green innovations in manufacturing through enhancing information management. This shows how sustainability spurs innovation. Furthermore, Hanaysha et al. [28] demonstrated that various innovation capabilities, including product, service, process, and marketing innovations, significantly improve SMEs' business sustainability. Innovativeness is key. In the telecom industry, innovations like virtualization, renewable energy systems, and e-waste recycling advance sustainability while improving efficiency and costs. For instance, virtualization reduces power and land needs for network infrastructure. In summary, studies across various contexts indicate that pursuing green innovations and efficiency improvements allows companies to reduce their environmental footprints and strengthen sustainability performance. This provides incentives for telecoms to develop innovative solutions. The fifth hypothesis is thus written as follows:

H5: *Innovation and efficiency gains constitute a factor driving sustainable development adoption (SDA) in the telecommunications industry.*

2.6. Long-Term Viability and Risk Mitigation

Adopting sustainable practices helps telecom companies mitigate risks, ensure business continuity, and support long-term viability. Sustainability strengthens resilience to potential disruptions. Aziz et al. [29] argued that integrating sustainability into enterprise risk management is crucial for long-term survival. Managing sustainability risks protects the future. Giannakis and Papadopoulos [30] found high interconnectivity between sustainability risks across environmental, social, and economic dimensions. This requires integrated risk management for effective sustainability strategies. Dias et al. [31] established that structured supply chain risk management processes contribute to automotive industry sustainability by identifying and mitigating vulnerabilities. Olbrich et al. [32] determined that financial risk management has an inverse relationship with sustainability in cattle farming. Production strategies better support viability. Furthermore, Ural [33] highlighted that tourism destinations need risk management to manage disasters and sustain the industry. Planning reduces vulnerability. For telecoms, sustainability helps to mitigate risks like supply chain disruptions, reputation damage, regulatory non-compliance, and infrastructure damage from extreme weather. It also ensures business viability as resources become scarcer. In summary, research shows sustainability adoption allows companies to identify and manage relevant risks, enhancing resilience. This supports long-term viability across industries. Therefore, the sixth hypothesis was outlined as follows:

H6: *Long-term viability and risk mitigation constitute a factor driving sustainable development adoption (SDA) in the telecommunications industry.*

2.7. Investor and Financial Community Pressure

Institutional investors and the broader financial community are increasingly pressuring telecom companies to improve sustainability performance. Their influence as shareholders and lenders pushes corporate action. García-Sánchez et al. [34] found that institutional investors promote the hiring of sustainability assurance services, which enhances transparency. This satisfies investor demands for sustainability information. García-Sánchez et al. [35] determined institutional ownership boosts corporate disclosure aligning strategy with sustainable development goals. Investors compel SDG alignment. Gold and Taib [36] showed that activist investors play a critical role in driving extensive sustainability practices at firms globally. Their pressure is influential. Gibson et al. [37] established that institutions with stronger sustainability characteristics in portfolios outperform those that do not, reflecting growing investor sustainability preferences. This reshapes investment. Velte [38] reviewed research showing that long-term and sustainable institutional investors improve corporate sustainability performance through their ownership positions. Furthermore, Al Breiki and Nobanee [39] argued that appropriate financial management and capital allocation are necessary to mitigate sustainability-related financial risks. Investors expect this prudence. In the telecom industry, top investors, like BlackRock and Vanguard, have emphasized sustainability, pressuring companies to act. Their vocal stances shape strategy. In summary, studies demonstrate institutional investors and the financial community compel telecoms and other companies to adopt sustainable practices through shareholder activism, capital stewardship, and lending policies. Therefore, the seventh hypothesis was formulated as follows:

H7: *Investor and financial community pressure constitute a factor driving sustainable development adoption (SDA) in the telecommunications industry.*

2.8. Cost and ROI Concerns

While sustainability initiatives offer many benefits, concerns over costs and return on investment can hinder adoption by telecom companies. Perceived financial barriers pose challenges. Humphrey et al. [40] found no performance difference between UK firms with high and low sustainability ratings. This indicates sustainability may not incur financial costs, despite perceptions. Ekins and Zenghelis [41] argued that conventional cost–benefit analyses often overstate the expenses of sustainability transitions by missing innovation gains. Short-term focus overlooks long-term payoffs. Ng and Rezaee [42] determined stronger sustainability performance lowers firms' cost of equity capital. However, some dimensions, like environmental practices, contribute more than others, like social ones. De Lange [43] showed that investors avoid sustainable startups, particularly in environmental dimensions. This highlights perceived cost barriers, though national context matters. Isaksson [44] explained that while sustainability provides economic benefits through quality gains, profit alone does not ensure sustainability. Broader indicators beyond surplus are needed. In the telecom industry, operators cite upfront costs, uncertain ROI, and earnings focus as constraints to sustainability initiatives. Overcoming the investment hurdle is key. While research shows sustainability's economic benefits often outweigh costs in the long run, perceived financial barriers can hinder adoption in the telecom industry. Firms focus on short-term returns. Therefore, the eighth hypothesis is written as follows:

H8: *Cost and ROI concerns constitute a factor constraining sustainable development adoption (SDA) in the telecommunications industry.*

2.9. Technological Limitations

While telecom companies aim to implement sustainability initiatives, technological barriers can hinder adoption and progress. Limitations of current technologies pose challenges. Kirchherr et al. [45] found that technological barriers were not highly ranked compared with cultural and market barriers to the circular economy transition in the EU. This indicates tech limitations are perceived rather than actual. Sebitosi and Pillay [46] argued that modern technologies alone will not solve rural electrification challenges in Africa without considering the social context. Techcentrism overlooks barriers. Huber and Hilty [47] explained that persuasive technologies aiming to encourage sustainable behaviors often assume information leads to action. This overlooks real adoption challenges. Purchase et al. [48] determined that technical factors, like waste processing abilities, quality control, and recovery processes, hamper circular economy adoption in construction. Immature technologies obstruct progress. In telecommunications, limitations cited include insufficiently efficient renewable power, recycling difficulties, and immature virtualization. But innovations are rapidly advancing to overcome these. In summary, while technological obstacles to sustainability implementation exist, research shows that social, cultural, and market barriers are often greater challenges. Furthermore, technologies are rapidly evolving to enable adoption. Therefore, the ninth hypothesis considered was as follows:

H9: *Technological limitations constitute a factor constraining sustainable development adoption (SDA) in the telecommunications industry.*

2.10. Global Supply Chain Complexity

Telecom companies operate highly complex global supply chains spanning multiple countries, tiers, and thousands of suppliers. This vast complexity creates significant barriers to implementing and monitoring sustainability practices. Sayed et al. [49] found that heterogeneity in institutional pressures and logics across supply chain tiers limits sustainable supply chain management to incremental changes. Misalignment obstructs collaboration needed for transformational sustainability. Chand et al. [50] determined that supply chain complexity poses risks to efficiency, costs, delivery, and customer satisfaction. It also complicates coordinating the many interconnected drivers of sustainable and complex supply chains. Tachizawa and Wong [51] argued that traditional sustainability governance is insufficient for complex global networks with numerous dispersed suppliers. Complexity reduces accountability across fragmented supply chains. Busse et al. [52] explained that complexity-driven uncertainty and information gaps prevent buying firms from monitoring sustainability in supply chains. This allows unsustainable practices to occur undetected. Gružauskas and Burinskienė [53] posited that food supply chains must adapt to growing consumer demand complexity through digitization, collaboration, and better management. Sustainability requires supply chain flexibility. Furthermore, Kim and Davis [54] found that global firms with larger, more dispersed supply chains were less able to trace conflict minerals due to limited visibility. Broad outsourcing impedes sustainability oversight. Similar trends are visible in telecoms. Macchion et al. [55] determined the substantial complexity across multiple supply chain tiers requires different sustainability practices for each level. This makes coordination very difficult. Research clearly demonstrates that vast complexity across global telecom supply chains limits visibility, enables unsustainable practices to go undetected, and hinders the collaboration needed for transformational sustainability. Therefore, the tenth hypothesis of this study is written as follows:

H10: *Global supply chain complexity is a factor constraining sustainable development adoption (SDA) in the telecommunications industry.*

2.11. Competitive Pressures

While sustainability can provide competitive advantages, intense competition in the telecom industry also creates pressures that hinder the adoption of responsible practices. Short-term survival imperatives take priority. Moreira et al. [56] found that competitive

pressures did not significantly moderate the link between green supply chain practices and environmental performance in Portuguese plastics firms. However, competitive intensity still poses adoption challenges. Tyler et al. [57] determined that perceived weaker competition prompted SMEs across four countries to further adopt environmental practices, while stronger competition shifted focus to maximizing financial returns. Yenipazarli [58] demonstrated through an economic model that competitive actions influence firms' incentives to conduct environmental R&D. Rivals' stances shape sustainability investment viability. Pulido-Fernández et al. [59] empirically found that at the macro level, progress in tourism sustainability does not constrain industry profitability, competitiveness, or development. However, effective communication is essential. In the telecom industry, fierce competition over subscribers and rapid technology cycles fuel short-term, earnings-driven thinking. But sustainability-focused players, like T-Mobile US, can gain advantages over less responsible rivals. While research shows that sustainability does not inherently undermine competitiveness, intense competition can still hinder telecoms from making needed long-term investments in sustainable transformation. However, sustainability-linked competitive differentiation is possible with proper strategy. Therefore, the eleventh hypothesis investigated was as follows:

H11: *Competitive pressures constitute a factor constraining sustainable development adoption (SDA) in the telecommunications industry.*

2.12. Lack of Awareness and Commitment

Limited awareness of sustainability issues and weak organizational commitment hinder the adoption of sustainable practices in telecom companies. Building knowledge and dedication to responsible business is essential. Ng and Lo [60] found that flipped classrooms and gamification increased student achievement and engagement with sustainable learning during the pandemic. This demonstrates that innovative approaches can raise sustainability awareness. Fitriani and Ajayi [61] identified a lack of knowledge and standards as a major barrier to sustainable construction in Indonesia. Poor awareness obstructs progress across industries. Ikediashi et al. [62] determined that the top three barriers to sustainable facilities management in Nigeria were a lack of training, regulation awareness, and general awareness. Education is key.

Khan and Henderson [63] showed that less than half of instructors were even aware their university courses were designated as sustainability-focused. None fully met the criteria, indicating limited commitment. In telecoms, many leaders acknowledge sustainability importance but lack the detailed understanding needed to transform operations. For example, only 29% of telecom CEOs can define scope 3 emissions, indicating an awareness gap. Research across regions and industries emphasizes that constrained sustainability awareness and weak organizational commitment are significant adoption barriers. Telecoms must prioritize education and engagement. Therefore, the twelfth hypothesis investigated was as follows:

H12: *Lack of awareness and commitment constitute a factor constraining sustainable development adoption (SDA) in the telecommunications industry.*

According to the twelve hypotheses of this study, regulatory pressures, stakeholder expectations, resource scarcity, competitive advantage, innovation gains, long-term viability, and investor and financial community pressure were considered the drivers of SDA in the telecommunications industry and the cost and ROI concerns, technological limitations, global supply chain complexity, competitive pressures, and lack of awareness and commitment were considered as the constraints of SDA in the telecommunications industry. Figure 1 shows the theoretical framework of this study.

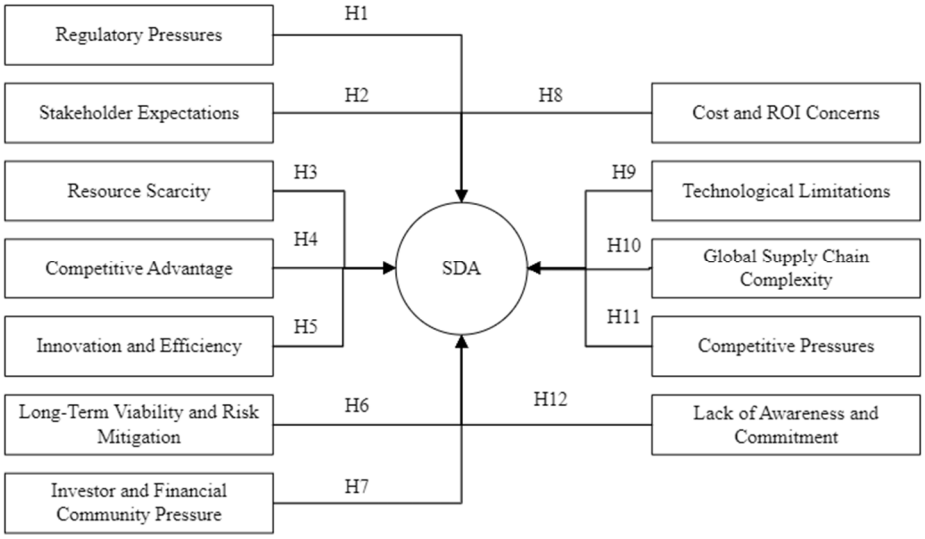

Figure 1. The proposed theoretical framework of the current study.

3. Methodology

This study adopted a quantitative research design to investigate the drivers and constraints of sustainable development adoption in the high-tech telecommunications industry. The quantitative approach allows for the systematic analysis of data and the identification of relationships between variables. A cross-sectional design will be employed to gather data from participants at a specific point in time, providing insights into their perceptions and attitudes toward sustainable development practices.

3.1. Study Variables

3.1.1. Dependent Variable

The dependent variable in this study was "Sustainable Development Adoption (SDA) in the telecommunications industry". It represents the extent to which sustainable development practices are embraced and integrated by telecommunications companies within their operations and strategies.

3.1.2. Independent Variables

1. Regulatory pressures: this independent variable assesses the impact of regulatory pressures on SDA within the telecommunications industry; it explores how government policies and regulations influence the industry's commitment to sustainable practices.

2. Stakeholder expectations: stakeholder expectations constitute another independent variable that examines how the perceived desires and demands of stakeholders, including customers, investors, and advocacy groups drive SDA in the telecommunications sector.

3. Resource scarcity and cost concerns: this variable combines resource scarcity and cost concerns to assess their influence on SDA; it explores whether the industry's awareness of resource limitations and cost implications motivates or hinders sustainability efforts.

4. Competitive advantage: competitive advantage as an independent variable investigates how companies in the telecommunications sector leverage sustainability practices to gain a competitive edge in the market, contributing to SDA.

5. Innovation and efficiency gains: this variable examines the role of innovation and efficiency gains in driving SDA; it assesses whether companies adopt sustainable practices for the purpose of improving their innovation capabilities and operational efficiency.

6. Long-term viability and risk mitigation: long-term viability and risk mitigation is an independent variable that evaluates whether companies perceive sustainability as a means to ensure their long-term survival and manage risks effectively.

7. Investor and financial community pressure: this variable explores how pressure from investors and the financial community influences SDA; it assesses whether financial

stakeholders prioritize sustainability in their investment decisions, driving companies to adopt sustainable practices.

8. Cost and ROI concerns: as an independent variable, cost and ROI concerns examine whether worries about the expenses associated with sustainability initiatives and their return on investment serve as constraints on SDA.

9. Technological limitations: technological limitations assess the extent to which constraints related to technological capabilities hinder SDA within the telecommunications industry.

10. Global supply chain complexity: this variable explores the influence of global supply chain complexity on SDA; it examines whether the intricacies of supply chain management affect the industry's sustainability efforts.

11. Competitive pressures: competitive pressures, as an independent variable, assess whether the desire to outperform industry peers and meet competitive standards serves as a constraint on SDA.

12. Lack of awareness and commitment: the independent variable of lack of awareness and commitment evaluates whether a general absence of awareness about sustainability issues and a lack of organizational commitment pose constraints on SDA within the telecommunications sector.

These independent variables are essential in understanding the drivers and constraints that influence the adoption of sustainable development practices within the telecommunications industry, as outlined by the study's hypotheses.

3.2. Participants and Sampling

The target population for this study consisted of managers, engineers, technicians, and interns working in high-tech companies representing different key players in the telecommunications industry ecosystem. The total number of participants was 1430, who were drawn from South Korea, Albania, Russia, and France. Participants' roles in their respective organizations made them relevant sources of information regarding sustainable development adoption in the telecommunications sector. Sampling was conducted using purposive sampling to ensure the representation of key players in the telecommunications ecosystem. The selected participants will be managers, engineers, technicians, and interns from telecom operators, device manufacturers, technology providers, and content and service providers. These companies encompass a diverse range of businesses, including telecommunications companies, mobile network operators, Internet service providers (ISPs), fixed-line operators, smartphone manufacturers, modem and router companies, software vendors, content providers, and app developers.

3.3. Data Collection

Primary data were collected through a structured survey questionnaire specifically designed to assess the drivers and constraints of sustainable development adoption in the high-tech telecommunications industry. Therefore, a questionnaire was designed based on relevant literature and employed a 5-point Likert scale to gauge participants' perspectives on various factors that influenced sustainable development practices (see Table A1 in Appendix A). Data collection took place from January to May 2023 through email. During the data collection process, participants were contacted through email, and the structured survey questionnaire was sent to them electronically. Participants received an email invitation with a link or attachment to the questionnaire, allowing them to respond at their convenience. This digital distribution method facilitated efficient data collection, enabling participants to complete the survey online and submit their responses electronically, and it ensured a systematic and timely approach to gathering data from a geographically diverse pool of respondents.

Throughout the course of this research, a rigorous methodological approach was diligently adhered to across all participating countries, namely, South Korea, Albania, Russia, and France. Consistency was maintained in all processes and procedures, spanning from the meticulous sampling methodology, which ensured the representation of key

telecommunications industry players, to the established criteria for participant selection. Additionally, uniform data collection procedures were meticulously followed across these diverse geographical regions, demonstrating a commitment to methodological integrity and facilitating robust cross-country comparisons.

3.4. Data Analysis

The data analysis involved two main stages. First, structural equation modeling (SEM) using AMOS 27.0.0 software was conducted to test the formulated hypotheses. SEM is suitable for analyzing complex relationships between latent constructs and observed variables, providing a comprehensive understanding of the drivers and constraints of sustainable development adoption. Second, sensitivity analysis was performed using multilayer perceptron (MLP) in SPSS. MLP, as an artificial neural network model, is well-suited for sensitivity analysis, allowing for the identification of influential variables and capturing non-linear relationships in the dataset.

4. Results

Figure 2 illustrates the distribution of participants across different roles within the telecommunications ecosystem, organized by country. The figure presents the number of participants from South Korea, Albania, Russia, and France, categorized into four key ecosystem roles: telecom operators, device manufacturers, technology providers, and content and service providers.

In addition to Figure 2, Table 1 provides a comprehensive breakdown of the demographic characteristics of the participants. The table includes several factors influencing the participant pool, such as gender, age, education, position, and country. The percentage of male participants stood at 67%, while females made up 33% of the total. Regarding age distribution, the largest segment fell within the 30–40 age group, constituting 37% of the participants, followed by the 20–30 age group with 22%. Participants above 50 years old comprised 19% of the sample.

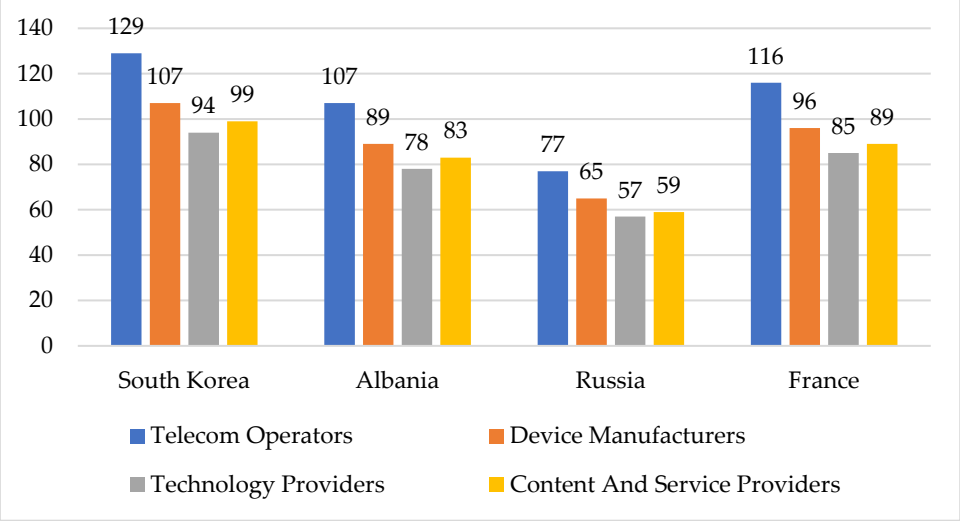

Figure 2. Number of participants from each country based on their role in the ecosystem.

Regarding educational backgrounds, 65% of participants had obtained a Master's degree, while 23% held a Bachelor's degree and 12% possessed a PhD. The education level of participants is crucial as it can influence the depth of their understanding, critical thinking abilities, and the nuance in their responses, providing valuable insights into the drivers and constraints of sustainable development adoption in the telecommunications industry. As for participants' positions within their respective companies, managers represented the highest percentage at 45%, followed by engineers at 28%, technicians at 17%, and interns

at 10%. Furthermore, Figure 2 highlights the country-wise distribution of participants, indicating the percentage representation of each country in the overall participant pool. South Korea and France each contributed 30% of the total participants, while Albania and Russia accounted for 20% each.

By examining both Figure 2 and Table 1, researchers gain valuable insights into the diversity and representation of participants in the study. The data provide a comprehensive overview of the participants' roles within the telecommunications ecosystem, as well as their demographic characteristics. These findings are crucial for ensuring the validity and generalizability of the research results, as they capture the perspectives of key players from different countries and roles, enriching the study's ecosystem approach and contributing to a more comprehensive understanding of environmental sustainability adoption within the telecommunications industry.

Table 1. Demographic characteristics of the participants.

Factor	Features	Percentage	Factor	Features	Percentage
Gender	Male	67%	Ecosystem role	Telecom operators	30%
	Female	33%		Device manufacturers	25%
Age	20–30	22%		Technology providers	22%
	30–40	37%		Content and service providers	23%
	40–50	22%	Sector	Telecommunications companies	10%
	Over 50	19%		Mobile network operators	6%
Education	Bachelor	23%		Internet service providers (ISPs)	9%
	Master	65%		Fixed-line operators	5%
	PhD	12%		Smartphone manufacturers	12%
Position	Manager	45%		Modem and router companies	13%
	Engineer	28%		Software vendors	22%
	Technician	17%		Content providers	11%
	Intern	10%		App developers	12%
Country	South Korea	30%			
	Albania	20%			
	Russia	20%			
	France	30%			

Table 2 presents the results of the validity and reliability tests conducted to assess the psychometric properties of the measurement scales used in the study. These tests are crucial for ensuring the robustness and accuracy of the data collected for each factor. The three main indicators evaluated in the table are Cronbach's alpha, composite reliability (CR), and average variance extracted (AVE).

Table 2. Validity and reliability test results.

Factors	Cronbach's Alpha	CR	AVE
Regulatory pressures	0.856	0.888	0.837
Stakeholder expectations	0.877	0.912	0.751
Resource scarcity and cost concerns	0.842	0.908	0.699
Competitive advantage	0.895	0.946	0.867
Innovation and efficiency gains	0.816	0.914	0.865
Long-term viability and risk mitigation	0.872	0.912	0.857
Investor and financial community pressure	0.753	0.804	0.873
Cost and ROI concerns	0.915	0.922	0.706
Technological limitations	0.845	0.905	0.806
Global supply chain complexity	0.824	0.885	0.837
Competitive pressures	0.760	0.808	0.736
Lack of awareness and commitment	0.758	0.81	0.81

Table 2 shows that all factors demonstrated commendable Cronbach's alpha values, ranging from 0.753 to 0.915. These values comfortably surpass the commonly accepted threshold of 0.7, indicating high internal consistency and reliability of the measurement items within each factor. In addition, all factors exhibited excellent CR values, ranging from 0.804 to 0.946. These values notably exceed the recommended threshold of 0.7, affirming the high reliability and consistency of the measurement items within each factor. The AVE measures the variance captured by the measurement items relative to the total variance of the underlying construct. It evaluates the convergent validity of the measurement scale, indicating the extent to which the items effectively represent the underlying factor. In Table 2, all factors demonstrated robust convergent validity, with AVE values ranging from 0.699 to 0.873. These values comfortably surpass the commonly accepted threshold of 0.5, indicating strong convergent validity and affirming the effective representation of the factors by the measurement items.

In assessing the suitability of the loading factors for inclusion in the final model for hypothesis testing, it is imperative that each loading factor associated with the questionnaire items surpasses the threshold of 0.7. Furthermore, the statistical significance of these factors is crucial for ensuring the robustness of the model. The results presented in Table A2 (in Appendix B) unequivocally demonstrate that all the loading factors in this research not only exceeded the stipulated threshold but also exhibited statistical significance. This pivotal validation ensured the reliability and relevance of the selected questionnaire items, reaffirming their suitability for the comprehensive SEM analysis conducted in this study.

Table 3 presents the matrix of intercorrelations, illustrating the degree of association between the factors investigated in the study. Correlation coefficients, which range from −1 to +1, reveal the nature and strength of relationships between pairs of factors. A positive correlation indicates a direct relationship, a negative correlation indicates an inverse relationship, and a value close to 0 suggests a weak or no correlation. Upon examining the correlation matrix, it is evident that the correlation coefficients between the variables were less than 0.5. This finding led us to conclude that the variables were not strongly correlated. In other words, the intercorrelations between the factors were relatively weak, suggesting that they operated independently and may have unique influences on environmental sustainability adoption within the telecommunications industry. These findings had significant implications for the conceptual framework of the study. The weak intercorrelations between the factors suggest that each factor may independently contribute to the adoption of environmental sustainability practices in the telecommunications industry. The lack of strong associations indicates that multiple factors played distinct and possibly complementary roles in influencing sustainability decisions within the ecosystem.

Table 3. The matrix of intercorrelations.

	RP [1]	SE [2]	RSCC [3]	CA [4]	IEG [5]	LTVRM [6]	IFCP [7]	CRC [8]	TL [9]	GSCC [10]	CP [11]	LAC [12]
RP	1											
SE	0.281	1										
RSCC	0.354	0.466	1									
CA	0.384	0.412	0.352	1								
IEG	0.362	0.364	0.535	0.298	1							
LTVRM	0.504	0.525	0.306	0.496	0.496	1						
IFCP	0.513	0.378	0.426	0.458	0.373	0.482	1					
CRC	0.501	0.511	0.441	0.483	0.498	0.564	0.521	1				
TL	0.302	0.411	0.499	0.336	0.500	0.383	0.285	0.371	1			
GSCC	0.339	0.370	0.529	0.551	0.401	0.408	0.480	0.510	0.392	1		
CP	0.400	0.568	0.509	0.325	0.553	0.380	0.356	0.565	0.297	0.488	1	
LAC	0.29	0.29	0.216	0.51	0.4	0.476	0.43	0.37	0.37	0.283	0.49	1

[1] RP—regulatory pressures. [2] SE—stakeholder expectations. [3] RSCC—resource scarcity and cost concerns. [4] CA—competitive advantage. [5] IEG—innovation and efficiency gains. [6] LTVRM—long-term viability and risk mitigation. [7] IFCP—investor and financial community pressure. [8] CRC—cost and ROI concerns. [9] TL—technological limitations. [10] GSCC—global supply chain complexity. [11] CP—competitive pressures. [12] LAC—lack of awareness and commitment.

The model fit test results (Table 4) indicate that the proposed statistical model reasonably fit the observed data. The X^2/df ratio was 1.72, suggesting a moderately good fit. The goodness-of-fit index (GFI) was 0.891, representing the model's ability to account for approximately 89.1% of the variance in the observed data. The adjusted goodness-of-fit index (AGFI) was 0.899, providing a conservative estimate of the model fit, with around 89.9% of what would be expected in a perfectly fitted model. While the model shows a reasonably good fit, there might be some room for improvement to achieve a more precise representation of the data.

Table 4. Model fit test results.

Fit Metrics	The Model's Value
X^2/df	1.72
GFI	0.891
AGFI	0.899

Table 5 presents the results of the hypothesis tests, which aimed to investigate the factors driving and constraining sustainable development adoption (SDA) in the telecommunications industry. This study examined twelve hypotheses that explored the relationships between specific factors and SDA within the industry.

Table 5. Hypotheses test results.

	Hypotheses	Estimates	*p*-Value	Standardized	Result
Drivers	H1: Regulatory pressures → SDA	0.393	0.017	0.384	Confirmed
	H2: Stakeholder expectations → SDA	0.411	0.020	0.391	Confirmed
	H3: Resource scarcity and cost concerns → SDA	0.496	0.083	0.476	Not confirmed
	H4: Competitive advantage → SDA	0.372	0.006	0.351	Confirmed
	H5: Innovation and efficiency gains → SDA	0.614	0.092	0.597	Not confirmed
	H6: Long-term viability and risk mitigation → SDA	0.550	0.001	0.532	Confirmed
	H7: Investor and financial community pressure → SDA	0.598	0.010	0.578	Confirmed
Constraints	H8: Cost and ROI concerns → SDA	−0.352	0.005	−0.344	Confirmed
	H9: Technological limitations → SDA	−0.408	0.073	−0.402	Not confirmed
	H10: Global supply chain complexity → SDA	−0.537	0.032	−0.512	Confirmed
	H11: Competitive pressures → SDA	−0.400	0.019	−0.388	Confirmed
	H12: Lack of awareness and commitment → SDA	−0.455	0.065	−0.432	Not confirmed

For the drivers of SDA, the study found strong evidence supporting the hypotheses H1, H2, H4, H6, and H7. Specifically, regulatory pressures (H1), stakeholder expectations (H2), competitive advantage (H4), long-term viability and risk mitigation (H6), and investor and financial community pressure (H7) were confirmed as significant drivers of sustainable development adoption. The estimates and *p*-values for these hypotheses indicate statistically significant relationships, and the standardized coefficients highlight the magnitude of their impact on SDA. However, the results were not as conclusive for hypotheses H3 and H5. Resource scarcity and cost concerns (H3) and innovation and efficiency gains (H5) did not show statistically significant relationships with SDA, as their *p*-values exceeded the significance threshold. While the estimates indicated positive associations, the lack of statistical significance suggests that these factors may not be significant drivers of sustainable development adoption in the telecommunications industry.

Regarding the constraints on SDA, this study found supporting evidence for hypotheses H8, H10, and H11. Cost and ROI concerns (H8), global supply chain complexity (H10), and competitive pressures (H11) were confirmed as significant constraints on sustainable development adoption. The negative estimates and statistically significant *p*-values indicate that these factors negatively influenced SDA in the telecommunications industry. However, hypotheses H9 and H12 did not find strong support as constraints on SDA. Technological limitations (H9) and lack of awareness and commitment (H12) showed non-significant relationships with SDA, as their *p*-values exceeded the significance threshold. Although their estimates indicated negative associations, the lack of statistical significance suggests that these factors may not be significant constraints on sustainable development adoption in the industry.

In this phase of the study, we employed a multilayer perceptron (MLP), which is an artificial neural network model, to assess the importance of each variable (both drivers and constraints) that influenced SDA in the telecommunications industry. We first conducted a root-mean-squared error (RMSE) test to evaluate the model's performance using different numbers of neurons in the hidden layer. The results of the RMSE test are summarized in Table 6. The RMSE test evaluated the performance of the MLP model in both the training and testing phases for each variable. The table presents the RMSE values for various neuron configurations in the hidden layer. For instance, considering regulatory pressures, when two neurons were used in the hidden layer, the RMSE values were 0.24 for the training phase and 0.18 for the testing phase. Similar results were observed for different neuron configurations for each factor.

Table 6. RMSE for different numbers of neurons in the hidden layer.

Factors	Neurons	RMSE		Factors	Neurons	RMSE	
		Training	Testing			Training	Testing
Regulatory pressures	2	0.24	0.18	Investor and financial community pressure	2	0.24	0.20
Regulatory pressures	3	0.24	0.27	Investor and financial community pressure	3	0.15	0.09
Regulatory pressures	4	0.26	0.28	Investor and financial community pressure	4	0.28	0.25
Stakeholder expectations	2	0.22	0.29	Cost and ROI concerns	2	0.08	0.05
Stakeholder expectations	3	0.06	0.12	Cost and ROI concerns	3	0.12	0.09
Stakeholder expectations	4	0.27	0.18	Cost and ROI concerns	4	0.15	0.29
Competitive advantage	2	0.26	0.24	Global supply chain complexity	2	0.27	0.25
Competitive advantage	3	0.17	0.22	Global supply chain complexity	3	0.21	0.23
Competitive advantage	4	0.15	0.06	Global supply chain complexity	4	0.18	0.23
Long-term viability and risk mitigation	2	0.08	0.07	Competitive pressures	2	0.12	0.17
Long-term viability and risk mitigation	3	0.11	0.29	Competitive pressures	3	0.16	0.07
Long-term viability and risk mitigation	4	0.28	0.13	Competitive pressures	4	0.2	0.13

Subsequently, we conducted a sensitivity analysis using the MLP model to determine the relative importance of the variables (drivers and constraints) on SDA. The sensitivity analysis results are presented in Table 7, showing the normalized importance scores for each factor.

Table 7. Sensitivity analysis results.

Factors	Normalized Importance
Stakeholder expectations	1.000
Competitive advantage	0.424
Regulatory pressures	0.257
Competitive pressures	0.145
Global supply chain complexity	0.133
Cost and ROI concerns	0.094
Investor and financial community pressure	0.056
Long-term viability and risk mitigation	0.020

According to the sensitivity analysis, stakeholder expectations emerged as the most influential factor, obtaining the highest normalized importance score of 1.000. This suggests that stakeholder expectations played a critical role in driving sustainable development adoption within the telecommunications industry. Following stakeholder expectations, competitive advantage ranked second in significance, with a normalized importance score of 0.424. This finding highlights the importance of competitive advantage as a key driver in influencing SDA practices within the industry. Regulatory pressures obtained a moderate normalized importance score of 0.257, positioning it as the third most influential factor. Although not as dominant as stakeholder expectations and competitive advantage, regulatory pressures still held notable importance in shaping sustainable development initiatives in the telecommunications sector. Additionally, the analysis revealed that competitive pressures and global supply chain complexity garnered normalized importance scores of 0.145 and 0.133, respectively, indicating their relatively significant impact on sustainable development adoption. On the other hand, the factors of cost and ROI concerns, investor and financial community pressure, and long-term viability and risk mitigation showed comparatively lower normalized importance scores of 0.094, 0.056, and 0.020, respectively, signifying a relatively lesser influence on SDA within the telecommunications industry. The results of the sensitivity analysis offer valuable insights into the hierarchical importance of each variable in driving sustainable development adoption in the telecommunications sector. Stakeholder expectations and competitive advantage emerged as the most influential drivers, emphasizing the significance of considering stakeholder demands and maintaining a competitive edge in promoting environmental sustainability.

5. Discussion

In this study, we aimed to investigate the drivers and constraints of sustainable development adoption (SDA) in the high-tech telecommunications industry. The research objectives were to identify the key factors influencing SDA and explore how different ecosystem players contribute to sustainability practices. This study employed a quantitative research design, using a structured survey questionnaire to collect data from 1430 participants representing various roles in high-tech companies across South Korea, Albania, Russia, and France. The data analysis involved structural equation modeling (SEM) and multilayer perceptron (MLP) to test hypotheses and perform sensitivity analysis, respectively.

Confirmation of the significant positive effect of regulatory pressures is consistent with and expands upon previous research on the role of government mandates in the telecom sector. Ojo and Fauzi [64] ranked regulations as the second most influential sustainability driver for Nigerian operators after cost savings. Our multi-country industry-level analysis reinforced this finding with more robust statistical testing, highlighting that compliance requirements enacted through policies and legislation are a key coercive force shaping the adoption of responsible social and environmental practices on a global scale. Mandates make sustainability an imperative by establishing baseline expectations linked to licensing and market access. Likewise, the finding that stakeholder expectations encourage sustainability uptake aligns with and builds upon prior evidence that customer, investor, and special interest groups actively pressure telecom firms to address sustainability concerns.

As demonstrated in Meixell and Luoma's [11] systematic review, different stakeholder groups leverage unique mechanisms like purchasing, financing, protests, or advocacy to compel action on issues like supply chains, e-waste, and greenhouse gases based on their particular interests. Our results confirm this relationship using broader empirical methods, underscoring that meeting the expectations of empowered stakeholders is critical for telecoms to maintain their societal license to operate, secure resources, and uphold their reputations. Proactively engaging concerned stakeholders also allows firms to obtain important feedback to guide sustainability strategies. Furthermore, the significant positive link between sustainability adoption and gaining competitive advantages mirrors conclusions from previous research both within and beyond telecommunications. Studies on how responsible practices grow customer and talent loyalty [21,65], drive innovation in services and operations [24], and enhance market positioning [23] highlight the strategic value proposition of sustainability across contexts. Our findings reinforce that sustainability differentiation also confers concrete benefits within the telecom sector, allowing responsible firms to stand out from competitors. First-mover advantages will likely accrue to leaders like T-Mobile US pursuing ambitious carbon reduction targets, renewable energy procurement, and e-waste programs relative to lagging peers. These market differentiators provide incentives to implement sustainability despite common constraints.

In terms of constraints, the significant negative effects of cost and ROI uncertainties, competitive intensity, and supply chain complexities corroborate key themes in the literature. Studies showed that sustainability initiatives often face skepticism due to perceived unfavorable or unclear profitability implications, both at the firm level [42] and for investors in startups pursuing sustainability models [43]. Our analysis verifies that these concerns pose barriers for telecoms as well, potentially discouraging investments despite evidence that economic benefits frequently outweigh costs. Competitive pressures also hinder adoption, consistent with research on how they divert focus toward maximizing short-term returns over responsible practices that require longer-term thinking [58]. Lastly, the accountability challenges created by complex global technology supply chains riddled with sustainability risks have been widely documented [52]. Our findings lend additional large-scale empirical support that such complexity reduces visibility into environmental and social practices that enable abuses.

Surprisingly, resource scarcity, innovation, technology limitations, and awareness had insignificant effects, warranting deeper investigation in future research. On the surface, resource scarcity and associated cost savings are expected to encourage telecoms to implement recycling, material efficiency, water conservation, and other responsible resource management practices. However, firms may already be pursuing basic resource efficiency improvements purely as a cost reduction tactic, meaning additional scarcity pressures do not necessarily influence sustainability strategies and mindsets at this stage. Furthermore, reducing material or energy footprints may have a limited impact on total expenses relative to other major operating costs like infrastructure and labor. If resource expenses are a small fraction of overall costs, their reduction will barely register on profitability analyses. This could downplay their role as a change agent. Moreover, resource scarcity risks, like rare earth mineral restrictions or water access, may not yet approach severe enough levels to necessitate proactive developments of circular business models the way climate change risks have for energy and emissions. Environmental projections on issues like droughts or depletion may simply underestimate timelines to acute shortages.

Regarding innovation and efficiency gains, the lack of significance seems counterintuitive. However, the mature telecom industry may have already harvested much of the low-hanging fruit in terms of environmental innovations and optimization of operations over decades of development. Unlike nascent green technology sectors, established telecoms have limited potential for additional major sustainability improvements from incremental efficiency gains alone without more fundamental business model transformation. The industry innovates rapidly, but innovations are focused on enhancing core network capabilities, speeds, reliability, and customer experiences rather than reducing en-

vironmental footprints specifically. Radical innovations tackling entrenched infrastructure and technology lifecycles holistically are imperative. But short-term profit-driven thinking predominates currently, limiting their pursuit.

Concerning technological limitations, factors like insufficient supplies of renewables, constraints on recycling, or virtualization difficulties may not acutely hinder sustainability adoption presently if other barriers like costs or complexity outweigh them. The technology landscape is also progressing so rapidly that limitations are constantly evolving. Emergent solutions like advanced solar panels, bio-based plastics, or digital twin applications that overcome past restrictions may already be mitigating these issues faster than anticipated. Constraints could thus be more temporary versus permanent obstacles. Technological cynicism likely prevails among telecom leaders grounded in legacy infrastructure paradigms. But transformative innovation pathways likely offer far more potential than they perceive if actively cultivated.

Lastly, the surprising insignificance of awareness and commitment could stem from sustainability knowledge and leadership engagement being more advanced than assumed. Public discourse, transparency demands, and stakeholder and regulatory pressures may have already elevated baseline awareness beyond dismal levels, even if gaps remain. Likewise, while there is certainly ample room for improvement, some evidence indicates an uptick in CEOs and boards prioritizing sustainability in rhetoric and policies if not yet in practice. The apparent disconnect between aspirations and implementation could be shrinking. Given the outsized influence of factors like costs, competition, and complexity on capital-intensive industries, awareness may not be an immediate binding constraint relative to these systemic barriers. Sustainability messaging alignment with performance is steadily improving nonetheless.

Adopting an ecosystem approach in studying SDA was shown to be highly significant. The telecommunications industry operates as a complex ecosystem comprising telecom operators, device manufacturers, technology providers, and content and service providers. Each ecosystem player plays a crucial role in promoting sustainable development practices. By understanding their interconnectedness and interdependencies, we gain valuable insights into how collaborative efforts among ecosystem players can drive sustainability initiatives.

This study analyzed the influence of different ecosystem roles on SDA. Telecom operators were found to have a substantial impact, given their position as key players in the industry by serving as conduits for sustainable practices across the ecosystem. Device manufacturers and technology providers also displayed significant contributions to SDA, leveraging their innovative capabilities to develop sustainable products and solutions. Content and service providers played a role in promoting sustainable services and applications within the industry. Exploring the interconnectedness and interdependencies among ecosystem players, we observed how collaborative initiatives and information sharing can lead to more robust sustainability practices. This highlights the importance of a holistic approach to sustainable development, involving all ecosystem players to collectively address environmental challenges.

This study also identified areas of divergence from previous research. The significance of certain constraints, such as cost and ROI concerns and technological limitations, may vary depending on the specific context and characteristics of the high-tech telecommunications industry. The current study contributes to the field by highlighting the importance of an ecosystem approach in understanding sustainable development adoption in the telecommunications sector. The findings emphasize the need for comprehensive strategies that involve all ecosystem players to foster sustainable practices and address environmental challenges effectively.

5.1. Theoretical Implications

The findings of this study have several theoretical implications that contribute to the existing literature on sustainable development adoption in the telecommunications

industry. These implications offer valuable insights into the drivers and constraints that influence the industry's commitment to sustainability and shed light on the interactions of ecosystem players in shaping sustainable practices.

First, this research extends the understanding of the multifaceted nature of sustainable development adoption. By investigating a wide range of drivers and constraints, we have provided a comprehensive overview of the factors that influence the industry's sustainable development efforts. The identification of both positive and negative influences on sustainable practices highlights the complexity of decision-making processes and underscores the need for a holistic approach to sustainability in the high-tech sector.

Second, our study emphasizes the significance of external forces in shaping sustainable development strategies. The positive influence of regulatory pressures, stakeholder expectations, financial community pressure, and competitive pressures highlights the role of external stakeholders in driving sustainable practices. This finding aligns with institutional theory, which posits that organizations respond to external pressures to conform to societal norms and expectations.

Third, our research highlights the importance of competitive advantage as a driver of sustainable development adoption. Organizations that perceive sustainability as a means of gaining a competitive edge are more likely to integrate sustainable practices into their core business strategies. This result contributes to the resource-based view of the firm, which suggests that sustainable resources and capabilities can lead to a sustained competitive advantage.

Fourth, this study identified supply chain complexity as a crucial factor influencing sustainable development adoption. The interactions and dependencies among supply chain partners can significantly impact the industry's ability to implement sustainable practices. This finding aligns with the growing body of literature on supply chain sustainability and underscores the importance of collaboration and coordination among supply chain players in achieving sustainability goals.

Fifth, this study highlights the need for increased awareness and commitment to sustainable development within the telecommunications industry. The lack of awareness and commitment emerged as a constraint that hinders the industry's progress toward sustainability. This finding emphasizes the role of internal organizational factors in driving sustainable practices and emphasizes the importance of promoting a culture of sustainability within companies.

Sixth, the research contributes to the theoretical understanding of resource scarcity and technological limitations as constraints to sustainable development adoption. While these factors did not show a direct influence on sustainability practices in the telecommunications industry, their identification opens avenues for further investigation and underscores the importance of addressing these constraints to enhance sustainable efforts.

Overall, the theoretical implications of this study contribute to the broader understanding of sustainable development adoption in the telecommunications industry. By integrating diverse theoretical perspectives and empirically testing their impact on sustainable practices, this research offers a nuanced understanding of the complex dynamics and interactions that influence the industry's commitment to sustainability. The identified drivers and constraints provide valuable guidance for academics, policymakers, and industry practitioners seeking to promote sustainable practices and navigate the challenges in the telecommunications sector. Ultimately, this research adds to the growing body of knowledge on sustainability in the high-tech industry and contributes to the advancement of theory in the field of sustainable development.

5.2. Managerial Implications

The findings of this study have important implications for managers in the telecommunications industry who are responsible for driving sustainable development adoption within their organizations. The identified drivers and constraints provide valuable insights

and actionable recommendations for shaping sustainable practices and navigating the challenges in this dynamic sector.

1. Embrace external pressures: Managers should recognize the significance of external pressures, such as regulatory requirements, stakeholder expectations, and financial community pressure, in driving sustainable development efforts. Embracing these pressures and proactively responding to them can position the organization as a responsible and forward-thinking industry player, enhancing its reputation and brand image.

2. Leverage competitive advantage: Sustainable practices can offer a competitive advantage in the telecommunications industry. Managers should view sustainability as an opportunity to differentiate their organization from competitors and gain a foothold in an increasingly environmentally conscious market. Integrating sustainability into the core business strategy can attract environmentally conscious customers and investors.

3. Foster supply chain collaboration: The study highlights the importance of addressing supply chain complexity in sustainable development adoption. Managers should foster collaboration and communication with supply chain partners to align sustainability goals and practices. Establishing sustainability criteria for suppliers and monitoring their compliance can contribute to a more sustainable and resilient supply chain.

4. Promote awareness and commitment: The lack of awareness and commitment emerged as a constraint to sustainable development adoption. Managers should prioritize initiatives that raise awareness among employees about the importance of sustainability and its potential benefits for the organization. Cultivating a culture of sustainability, backed by top management commitment, can foster employee engagement and motivation to contribute to sustainable practices.

5. Invest in innovation and efficiency: While innovation gains did not show a significant direct influence on sustainable practices, managers should recognize the potential long-term benefits of investing in innovative and efficient technologies. Integrating renewable energy sources, optimizing resource use, and embracing green technologies can lead to cost savings and improved environmental performance.

6. Address resource scarcity and technological limitations: Although not identified as significant drivers in this study, managers should be proactive in addressing resource scarcity and technological limitations. Investing in research and development to overcome technological barriers and exploring sustainable alternatives to resource-intensive processes can future-proof the organization against potential resource constraints.

7. Engage with the ecosystem: Managers should actively engage with various ecosystem players, including government agencies, industry associations, non-governmental organizations, and the local community, to promote sustainable development adoption. Collaborating with stakeholders and understanding their expectations can lead to more effective and targeted sustainability initiatives.

8. Develop metrics and reporting: To monitor and measure the impact of sustainable development efforts, managers should establish clear metrics and reporting mechanisms. Regularly tracking key performance indicators related to sustainability can help assess progress, identify areas for improvement, and communicate the organization's sustainability achievements to stakeholders.

9. Learning from sustainability-focused institutions: Managers can draw insights from higher education institutions that have committed to integrating sustainability issues into their curriculum. Understanding the challenges and successes of these institutions can provide valuable lessons for implementing sustainability-focused initiatives within the organization.

In conclusion, the managerial implications derived from this study offer practical guidance for telecommunications industry managers aiming to enhance sustainable development adoption. By addressing the identified drivers and constraints, fostering collaboration, and promoting a culture of sustainability, organizations in the telecommunications sector can position themselves as responsible industry leaders, achieve a competitive advantage, and contribute positively to environmental and social goals. Embracing sustainable

practices can not only benefit the organization's reputation and brand image but also drive long-term financial and environmental success.

5.3. Limitations and Future Research Recommendations

While this study provides valuable insights into the drivers and constraints of sustainable development adoption in the telecommunications industry, it is essential to acknowledge certain limitations that may have influenced the findings. These limitations open avenues for future research to build upon the current study and contribute to a more comprehensive understanding of sustainable practices in the high-tech sector.

1. Inclusion of stakeholder perspectives: While this study focused on managerial perceptions, sustainable development adoption is a multi-stakeholder process. Future research could consider incorporating the perspectives of various stakeholders, including customers, suppliers, and regulatory authorities, to provide a more comprehensive understanding of the challenges and opportunities in sustainable practices.

2. Contextual factors: The current study examined sustainable development adoption in the telecommunications industry as a whole without considering specific contextual factors that may vary across different countries or regions. Future research could explore how cultural, legal, and economic differences influence sustainable practices in the high-tech sector in various global settings.

3. Impact assessment: Investigating the actual environmental and social impact of sustainable development adoption in the telecommunications industry is an important area for future research. Assessing the tangible outcomes of sustainable practices, such as reductions in carbon emissions or improvements in community well-being, can provide valuable information on the overall effectiveness of sustainability initiatives.

6. Conclusions

Our research identified several key drivers that significantly influence sustainable development adoption in the telecommunications industry. These drivers have profound implications for the industry's sustainability efforts and its broader impact on society and the environment.

- **Regulatory pressures:** Recognizing the impact of regulatory pressures underscores the pivotal role of government policies in shaping sustainability practices within the industry. This finding highlights the need for policymakers to collaborate with industry leaders to develop and enforce regulations that promote sustainable practices, ultimately leading to a more environmentally friendly and socially responsible telecommunications sector.
- **Stakeholder expectations:** Understanding the influence of stakeholder expectations emphasizes the importance of engaging with a diverse range of stakeholders, including customers, investors, and advocacy groups. Companies that proactively address and align with stakeholder values and expectations are more likely to maintain their support and trust, fostering stronger relationships and a positive industry reputation.
- **Competitive advantage:** The recognition of competitive advantage as a driver signifies that sustainability is not just a social responsibility but also a strategic opportunity. Companies that integrate sustainable practices can gain a competitive edge in the market, stimulating innovation and driving economic growth while simultaneously advancing environmental and social goals.
- **Financial community pressure:** The influence of financial community pressure highlights a growing trend where investors consider sustainability criteria in their decision-making processes. Companies that prioritize sustainability may attract more investments and have access to capital at more favorable terms, which can significantly impact their financial stability and growth prospects.

- **Cost concerns:** The driver of cost concerns suggests that adopting sustainable practices can lead to long-term cost savings. This insight challenges the notion that sustainability initiatives are solely an expense, encouraging companies to view them as strategic investments that yield financial benefits while contributing to a more sustainable future.
- **Supply chain complexity:** Recognizing supply chain complexity as a driver underscores the critical role of transparency and sustainability efforts throughout the supply chain. Collaboration between companies and their suppliers is essential to ensure sustainable practices are upheld, reducing environmental and ethical risks and enhancing brand reputation.
- **Competitive pressures:** The impact of competitive pressures emphasizes that peer competition can drive continuous improvement in sustainability practices. As companies strive to stay ahead in terms of sustainability, they can collectively raise industry standards, contributing to a more environmentally conscious and ethical telecommunications sector.

These findings not only provide insights into the telecommunications industry but also offer actionable strategies that can shape the industry's commitment to sustainable development. By understanding these drivers and their implications, stakeholders, including industry leaders, policymakers, and investors, can work together to create a telecommunications sector that not only meets the demands of today but also ensures a more sustainable and responsible future.

Recommendations for Future Studies

- **In-depth exploration of constraints:** Future research should delve deeper into understanding the constraints that were found to have a limited direct impact on sustainable development adoption. Exploring the intricacies of resource scarcity, the potential for innovation gains, overcoming technological limitations, and strategies for enhancing awareness and commitment can shed more light on addressing these challenges.
- **Longitudinal studies:** Conducting longitudinal studies to track the evolving landscape of sustainable development in the telecommunications industry can provide valuable insights into how these dynamics change over time. This would enable a more comprehensive understanding of the industry's progress toward sustainability.
- **Comparative analysis:** Comparative analyses across different regions and telecommunications markets can reveal variations in sustainable development adoption strategies. Investigating how these factors operate in diverse contexts can provide a broader perspective on industry sustainability.
- **Behavioral studies:** Complementing quantitative data with qualitative research, such as behavioral studies and interviews, can offer deeper insights into the motivations and decision-making processes of industry players regarding sustainability. This could help to uncover underlying attitudes and beliefs that influence sustainable practices.
- **Advanced modeling:** Employing advanced modeling techniques and predictive analytics can help forecast future trends in sustainable development adoption within the telecommunications sector. These models can provide industry stakeholders with valuable insights for strategic planning.

This study contributes to the growing body of knowledge on sustainable development in the telecommunications industry. By shedding light on the roles and interactions of ecosystem players and identifying both driving factors and potential constraints, we hope to inspire meaningful actions that propel the industry toward a more sustainable future. It is our belief that the knowledge gained from this research will serve as a foundation for further advancements in sustainable practices and contribute to the broader global effort of creating a more sustainable and resilient high-tech sector.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available in the present article.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. The questionnaire items.

Drivers	1. Regulatory Pressures:
	(a) To what extent do you believe that regulatory pressures positively influence our company's adoption of sustainable development practices?
	(b) How well does our company align with the environmental regulations and policies set by the telecommunications industry?
	(c) To what degree does your role in the company involve complying with environmental regulations and sustainability standards?
	(d) How much importance do you believe the regulatory authorities place on companies adopting sustainable development practices in the telecommunications sector?
	2. Stakeholder Expectations:
	(a) How much influence do stakeholders (e.g., customers, investors, NGOs) exert on our company's commitment to sustainable development?
	(b) How well does our company address the sustainability expectations and demands of various stakeholders in the telecommunications industry?
	(c) To what extent do you perceive that stakeholders consider our company's sustainable development efforts when making decisions to engage with us?
	(d) How likely are stakeholders to support our company if we demonstrate strong commitment and progress in sustainable development practices?
	3. Resource Scarcity and Cost Concerns:
	(a) To what extent do you believe that resource scarcity affects our company's ability to invest in sustainable development initiatives?
	(b) How would you rate the cost implications associated with integrating sustainable development practices into our company's operations?
	(c) How likely are you to encounter budgetary constraints when proposing sustainability projects within our company?
	(d) To what extent do you think resource scarcity may hinder the successful implementation of sustainable development initiatives in our company?

Table A1. *Cont.*

	4. Competitive Advantage:
	(a) How well does our company leverage sustainable development practices to differentiate itself from competitors in the high-tech telecommunications market?
	(b) To what extent does the integration of sustainable development initiatives contribute to enhancing our company's market position and brand image?
	(c) How would you rate our company's competitive advantage compared to industry peers who have not fully embraced sustainable development practices?
	(d) How likely are customers to choose our products/services over competitors' offerings due to our strong commitment to sustainable development?
	5. Innovation and Efficiency Gains:
	(a) To what extent do you perceive that innovation and efficiency gains positively drive the adoption of sustainable development practices in our company?
	(b) How frequently do you encounter innovative solutions that contribute to environmental sustainability in our company?
	(c) How effective do you find the implementation of sustainable practices in optimizing resource efficiency within our company?
	(d) How likely are you to suggest innovative approaches to enhance our company's sustainable development initiatives?
	6. Long-Term Viability and Risk Mitigation:
	(a) How much importance does our company place on long-term viability and risk mitigation in the context of sustainable development?
	(b) How well does our company anticipate and address potential risks associated with sustainability-related challenges?
	(c) To what extent are long-term sustainability goals integrated into our company's strategic planning and decision-making processes?
	(d) How likely are you to consider the long-term impacts of sustainability actions when executing projects within our company?
	7. Investor and Financial Community Pressure:
	(a) To what extent do you believe that investor and financial community pressure positively influences our company's adoption of sustainable development practices?
	(b) How well does our company communicate its sustainable development efforts to investors and the financial community?
	(c) How likely are investors to prioritize companies with strong sustainable development performance in their investment decisions?
	(d) How much do you think the financial community's expectations influence our company's sustainable business practices and policies?
Constraints	8. Cost and ROI Concerns:
	(a) How much do cost and return on investment concerns hinder the adoption of sustainable development practices in our company?
	(b) How likely are cost considerations to be a major factor in decisions related to sustainable development initiatives?
	(c) To what extent do you believe that sustainability-related expenses may affect our company's financial performance in the short term?
	(d) How much do you think that the perceived return on investment of sustainable development initiatives influences decision-making within our company?

Table A1. *Cont.*

9. Technological Limitations:
(a) How significantly do technological limitations impact the implementation of sustainable development practices in our company?
(b) How likely are you to encounter technological barriers when attempting to integrate sustainable practices into our company's operations?
(c) To what extent do you believe that technological advancements are necessary to overcome existing barriers to sustainable development adoption?
(d) How much emphasis does our company place on technological innovation to support our sustainability initiatives?
10. Global Supply Chain Complexity:
(a) How much do challenges related to global supply chain complexity hinder the successful implementation of sustainable development initiatives within our company?
(b) How likely are supply chain complexities to be a major consideration when planning sustainability-related projects?
(c) To what extent do you believe that collaboration with supply chain partners is crucial to effectively address sustainability challenges?
(d) How much do you think that streamlining the global supply chain can positively impact our company's sustainable development efforts?
11. Competitive Pressures:
(a) How significantly do competitive pressures influence the constraints on adopting sustainable development practices in our company?
(b) How likely are you to perceive competitive pressures as a barrier to fully embracing sustainability initiatives?
(c) To what extent do you believe that industry competition impacts the priority placed on sustainability-related actions within our company?
(d) How much do you think that strong competition in the telecommunications sector affects our company's willingness to invest in sustainable development?
12. Lack of Awareness and Commitment:
(a) How much does a lack of awareness about sustainable development hinder its adoption in our company?
(b) How likely are you to encounter resistance or lack of commitment from stakeholders when promoting sustainable practices?
(c) To what extent do you believe that raising awareness and fostering a culture of sustainability are crucial for successful implementation?
(d) How much do you think that leadership commitment plays a role in addressing the lack of awareness and commitment towards sustainability initiatives?

Appendix B

Table A2. Loading factors for questionnaire items.

Items	Loading Factors	Mean	SD	*p*-Value
RP1	0.733	3.30	1.30	0.008
RP2	0.847	3.20	1.60	0.014
RP3	0.724	3.60	1.40	0.013
RP4	0.836	2.60	1.30	0.017
SE1	0.863	4.30	1.50	0.011
SE2	0.875	2.60	1.60	0.016
SE3	0.733	3.90	1.40	0.011
SE4	0.865	2.80	1.20	0.018

Table A2. *Cont.*

Items	Loading Factors	Mean	SD	*p*-Value
RSCC1	0.885	4.40	1.00	0.014
RSCC2	0.798	3.30	1.70	0.015
RSCC3	0.893	3.90	1.40	0.010
RSCC4	0.745	4.70	1.70	0.010
CA1	0.714	2.70	1.80	0.008
CA2	0.740	4.60	1.30	0.011
CA3	0.864	3.90	0.90	0.011
CA4	0.721	4.60	1.50	0.008
IEG1	0.795	2.90	1.20	0.013
IEG2	0.795	4.10	1.80	0.009
IEG3	0.755	2.70	1.40	0.011
IEG4	0.823	3.70	1.60	0.018
LTVRM1	0.756	4.50	1.30	0.012
LTVRM2	0.888	3.40	1.50	0.008
LTVRM3	0.819	3.00	1.50	0.014
LTVRM4	0.823	4.50	1.00	0.008
IFCP1	0.749	2.80	1.80	0.009
IFCP2	0.888	3.50	1.70	0.012
IFCP3	0.796	3.30	1.00	0.018
IFCP4	0.768	4.00	1.10	0.009
CRC1	0.757	3.30	1.30	0.012
CRC2	0.806	5.00	0.80	0.015
CRC3	0.795	3.30	1.20	0.013
CRC4	0.859	3.90	1.60	0.008
TL1	0.772	3.80	1.60	0.014
TL2	0.819	3.80	0.80	0.013
TL3	0.840	3.40	1.40	0.011
TL4	0.710	2.90	1.00	0.017
GSCC1	0.758	4.80	1.40	0.017
GSCC2	0.728	4.50	1.60	0.010
GSCC3	0.801	3.50	1.10	0.018
GSCC4	0.823	4.80	1.40	0.016
CP1	0.815	4.10	1.70	0.010
CP2	0.740	2.70	1.60	0.011
CP3	0.759	4.60	1.20	0.011
CP4	0.734	3.40	0.80	0.009
LAC1	0.825	2.50	1.30	0.008
LAC2	0.834	3.90	1.80	0.010
LAC3	0.782	4.60	1.70	0.014
LAC4	0.787	3.00	0.80	0.016

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