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Reconnoitering the Impact of Digital Technologies Adoption in Green Supply Chains Sustainability in Manufacturing Industry in Pakistan During COVID-19

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Abstract

In recent years, the rapid advancement of digital technologies has revolutionized supply chain management, enabling companies to optimize operations ones and achieve sustainability. The manufacturing sector in Pakistan has enjoyed considerable development in recent years, but sustainability remains an area of major concern. The adoption of digital technologies is seen as one possible way out of this predicament. This study explores the influencing Evaluations digital technology can have on supply chain sustainability for Pakistan's manufacturing enterprises. To achieve this, we have relied on quantitative methods of data collection. Data was obtained through 250 structured interviews of enterprise production managers by questionnaire. We observe from our findings how it is critical to introduce digital technologies into supply chain management if sustainability is to be improved. The results of this investigation lead us to conclude that manufacturing firms should consider the introduction of digital technologies in order to make their supply chains more efficient and sustainable. This paper has looked at how digital technologies can be used to optimize supply chain operations and enhance sustainability, contributing environments society economy. The researchers have also identified challenges and opportunities for the adoption of digital technologies. This will provide guidance to policy-makers managers expect of course, there are many example stakeholders in such decisions.

Keywords: Supply Chain Sustainability, Adoption, Digital Technologies, Manufacturing Firms, Pakistan.

1. Introduction

Businesses today are thus recognizing that they should design policies and procedures for responsibility particularly in their supply chains (Jones et al., 2021). We talk of supply chain sustainability when we consider using a man-managed industrial system that is both profitable and responsible (Marvuglia et al., 2022). If companies adopt the notion of sustainability, the opportunity exists to make sure there is a good chance its policies and practices are also ethical in nature as well as being friendly towards the environment (Singh et al., 2021). As a result, gaining an understanding of the part that digital technologies play in facilitating the achievement of supply chain sustainability is becoming increasingly important for businesses largely (Wen et al., 2021). This is particularly true for companies that are still seeking sustainability in their supply chains. In this blog article, we are going to discuss what supply chain sustainability is, the benefits of having such sustainability, and the role played by digital technologies; we will also look at some challenges companies loaded down with technology face in implementation, things to consider during software deployment in manufacturing enterprises and also give an example or two of successful practice as a kind of case study (Abou-foul et al., 2021). By "supply chain sustainability", we mean managing resources and processes all the way along a supply chain so that it is possible in economic, social terms also for the environment to benefit (Marshall et al., 2015). It is a plan that takes account of the product or service's whole life cycle, from receiving raw materials through production and distribution to ultimately persons using or touching it (Vezzoli et al., 2017). This approach is referred to as life cycle management. The behavior that a company pursues throughout

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its supply chains, not only does it foster business development but also makes the whole society more friendly for humans and closer to nature (Qamar & Ain, 2023). This goal may be attained by implementing measures such as: decreasing emissions creating environmentally friendly packaging ensuring that labor procedures are conducted ethically.

As environmental and social awareness has come up in recent years, the idea of environmentally sustainable supply chain practices has gained ground. This growing sentiment, on both counts of environmental and social concern, is thought to have played a critical role in the popularity of sustainable supply chain Environmental concern, in the form of reducing damage or harm to the environment and its ecosystems in general, is now something that companies for them Culprits who do not publish their environmental directives will and allowing these figures to accomplishments as well sub-consciously belies just how difficult it is to find that type of information As a result, major industrial powers such as Europe have enacted laws and regulations to keep companies moving towards sustainability (Gawęda, 2021). These rules and regulation are found in many countries around the globe A sustainable environment and carbon emissions decreased to a minimum are what companies need in order to keep up their competitive edge with competitors down the road (Karttunen et al., 2021). A lower cost is probably the least effort benefit a reader will get by adopting a more environmentally conscious approach towards brutality in the industry Well businesses they certainly can! By adopting more energy-conscious policies and procedures, companies may minimize the number of resources they use and waste they create; in the end this translates into reduced costs. Furthermore, companies can improve their public image by showing what a green-glowing ethos they have. Eventually that means enhanced customer loyalty and brand recognition. It is a win-win situation for all.

Further, the bottom line of a better corporation can benefit marginally from being able to start recording savings as more emphasis is placed on efficiency (Barus et al., 2017). And, as a result, companies are now able to place orders for that mainframe without taking up management time doing data entry at both ends of the supply chain. If that is not enough already, productivity is what technology aims for also because of lower costs. Called Track Date analysis software. Organizations are now more capable of making decisions at an earlier stage by using this method than they would have been otherwise. Additionally, organizations can use these technologies to know if potential threats exist within a supply chain (Brintrup et al., 2024). This allows organizations to take preventive measures about the probable dangers that have been shown to exist. It is possible that there will be benefits to firms from better working conditions for workers. And when companies carry out operations in a more sustainable manner, workstation labor must be valued and the work environment will be healthy and safe, ensuring that their workers are treated with decency (Schulte et al., 2022). This has scope to improve morale, which in turn could result in increased productivity and better service to the consumer. This could also boost morale still higher.

In order to create a supply chain that is both profitable and sustainable, at the same time, the requirements of all stakeholders at each level must be balanced. This balance needs to be struck throughout. We will lay out a method here to examine how digital technologies can be employed in supply chains for sustainability (Kamble et al., 2022). This was developed as part of our investigation into the subject. What we are particularly concerned with is the place where distributed ledger technology may have a role to play in this scheme. These technologies can feature in many different contexts, such as consumer interaction, data exchange, digital interfaces, and corporate information systems (Rana & Rana, 2024). This marks out the four dimensions. The study has established that they could spring from each of these directions to create either a plan which helps foster sustainable supply chains by for instance starting at any particular point on the compass and knitting in that area, on the critical case of knots where method meets reality. This enables us to elaborate how they could be accommodated in a plan that is supportive of sustainable supply chains.

2. Literature Review

Digital technologies, with their tried and tested applications, have been making developing a sustainable supply chain system essential (Chiappetta Jabbour et al., 2020). It is clearly important to understand that digital technologies are not just a tool but also a system enabler for improving supply chain processing efficiency and increasing the quality of products (services), lowering impacts on environment and creating new business models with scale benefits (Joyce & Paquin, 2016). There are various different methods in which these cutting-edge pieces of intelligent warehouse technology can help to enhance the efficiency of working. This technology assisted manufacturer process away out of sight. Our one might say that the result is a non-stop production line. But who is actually interested in figures for wastage of space during production line moving- Statistics claiming that goods are often mishandled in transmission between warehouse floors? In recent years, these technologies allow manufacturers to simulate optimal production output from warehouse feed to warehouse throughput. In this way they prevent (Abushaikha et al., 2018). They actually help manufacturers to make their warehouses more efficient through such simulations.

Moreover, the enterprise application makes it feasible to improve low-turnover product tracking, and the configuration of this option is facilitated by the data that is generated and the activity related to the various items that the organization or enterprise in question works with. This involves the speed of tracking, the amount of time that it is possible for a given entity to be missing in order for the enterprise to conclude that it has lost it. The system can inform the user of the number of the item in its database that is being sought. The searching process may be carried out either up or down within the scale, and it may be ceased at any moment. It also records the entire tracking activity, offering the users with information on how quickly the application can track a specific number when it is being employed, as well as how much downtime it is capable of tracking for a given entity. This would make it possible to create a “smart factory,” which would enable manufacturers and supply chain managers to determine the most efficient way to allocate which stock to reserve and which stock to keep moving through specific workflows or channels (Robinson Jr et al., 2005). In other words, a smart factory would allow for the creation of a “smart factory.” To put it another way, one might say that this would make it possible to build a “smart factory.”

Some systems are able to model at larger scales, which enables more possibilities for the optimization of network operations. Modeling may be used by manufacturers and warehouses to determine which transportation alternatives and distribution hubs are the most efficient and profitable. This can include determining which kind of strategic partnerships with third-party suppliers are likely to prove to be the most beneficial (Adobor & McMullen, 2014). The creation of hardware and software infrastructures that are able to support its projections is required in order to get the exact, real-time visibility that these technologies make available (Helo & Shamsuzzoha, 2020). Some of these needs can be met by internet design service companies, but in others cases the information needs of the business may require extensive investment by the business. Moreover, a concept framework needs to be built for the firm and kept online. In order to maximize the operational efficiency of businesses, different iterations of the development need to be considered in order to determine the combination of assets, resources, measurements, and other need to be stored. The iterations may be required to determine the combination of assets, resources, measurements, and other need to be stored.

2.1 Digital Transformation

It is not a secret that only a few businesses can successfully proceed to a digital transformation and benefit from using digital technology. There are a number of possible reasons that might be tested to determine if an organization will initiate a digital transformation. The results demonstrate that the businesses that realized the potential threat to their performance are now in a position not only to successfully transform a business using digital technology but also to realize it. Thus, it is noted that digital technology is likely to lead to the complete transformation of several industries. For example, both the publishing and the media sector had to go through significant changes in order to respond to the appearance of new digital technology that resulted in the destruction of the established economic models. However, changes were inevitable and allowed the industry to survive. Additionally, the market development of the existing market might also be envisaged with the current shift to a digital approach. To be more specific, the technology provides companies with the opportunity to expand their presence into new markets as well as to grow in the existing ones. In order to achieve the desirable outcomes, their business models might require minor modifications or significant changes. Alterations in the expectations of consumers are yet another possible cause of change in the digital realm. Customers who see comparable adjustments in other aspects of their lives may put pressure on companies to deliver more technologically advanced goods and services in response to these advances. This may be because customers are seeing these transitions in other aspects of their own lives (Hopkins et al., 2014).

2.2 Integrated Value Chain

Digital transformation in the context of the manufacturing industry, and came to the conclusion that in order for businesses to create value through digital transformation, they need to integrate a variety of cultures, processes, resource structures, and business strategies that are oriented towards the digital (Martínez-Caro et al., 2020) This was discovered after researching digital transformation in the context of the manufacturing industry. After doing study on the topic of digital transformation in the context of the manufacturing sector, this was the conclusion that was reached. All of the areas of corporate operations that have been covered up to this point should be included in a plan for digital transformation (Fischer et al., 2020). These aspects include, but are not limited to, product development, production, quality control, and distribution, among other things. It is not a blank slate since it must take into consideration the legacy systems and processes in order to recognize the likely problems and opportunities that may arise (Bennett et al., 1999). This indicates that it is not possible to begin from the very beginning. The process of digital transformation does not occur in a void but rather in the context of previous investments that have already been made in technologies and capacities into which new digital technologies will be incorporated (Song et al., 2023). Already, significant investments had been made in various technologies and capabilities, such as cloud computing, artificial intelligence, and machine learning. In addition to the innovation of existing products and services, businesses would pay more attention to the development of new markets, which ensures that they can "outcompete" their competition instead of just outperforming them. There are many different ways in which a digital transformation is able to create value, including but not limited to:

- Operational efficiency
- Better customer experiences
- Improved business models
- Strategic differentiation

2.3 Integrated Communication

Companies are considered to be digitally enabled if they have successfully integrated current information and communication technologies, often known as digital technologies, in order to develop new commercial opportunities and growth (Ketchen Jr et al., 2007). Back-office information technology systems now make use of a variety of contemporary forms of information and communications technology (ICT), including virtualization, mobile communication, and data analytics. A full digital representation of the organization, very similar to what one could find in a cyber-physical system, is now available because to the convergence of all of these technologies, which makes it possible to develop such a representation (Martins et al., 2023). As a consequence of the implementation of these technologies, a transition to a digital format is going to take place. In addition to this, they brought to light concerns that surfaced as a consequence of the competitive nature of the types of uses that made use of them. The relationship that companies have with their customers has to go through some significant changes before it can be considered healthy. Customers should be viewed as active players in the process since the insights they provide may have a (Ayinaddis et al., 2023).

2.4 Integrated Customer Interaction

Both digitalization and sterilization are important and complimentary business strategies that should be pursued concurrently by organizations who are involved in industrial production. The ever more intricate and fluid ties that businesses maintain with their clientele are made manageable only via the use of digital technology. They discovered positive impacts that were consistent with the findings of Jain et al. (2023) in regard to quality, efficiency, and the accompanying benefits

given to users. Businesses are able to develop new product features, reach greater levels of reliability and efficiency, and, as a whole, provide more value to customers who purchase their goods as a result of the incorporation of digital technology into the production environment. The writers also pointed out that the industrial sector has grown more interested in sterilization, which is made possible by digital technology, and as a result is investing more resources in the development of capacity for digitalization (Marti & Puertas, 2023). This was another point that they stated. The development of such talents may result in future developments, such as the production of "smart goods" via the integration of intelligence and remote control into conventional products, as well as enhanced data collecting and analytical capabilities.

2.5 Theatrical Framework

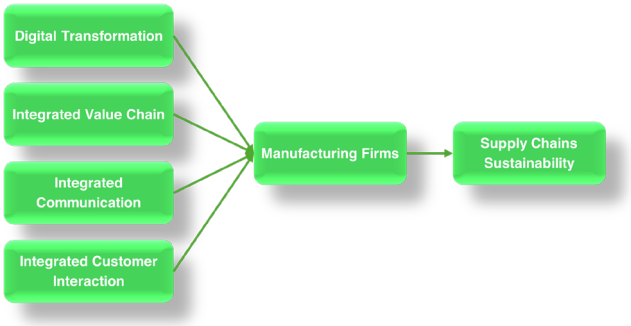

Figure 1: Theoretical Frameworks.

2.6 Hypothesis

H1: Digital transformation has significant impact on supply chain sustainability in manufacturing firms.
H2: Integrated Value has significant impact on supply chain sustainability in manufacturing firms
H3: Integrated communication has significant impact on supply chain sustainability in manufacturing firms.
H4: Integrated customer Interaction has significant impact on supply chain sustainability in manufacturing firms.

3. Methodology

In order to gather the primary data used for hypothesis validation, we employed a survey research methodology. Studies have shown that digitalization ideas are receiving considerable attention, yet the interaction of these ideas has been less explored. To collect data and conduct a sample procedure for the empirical research, we designed a questionnaire with input from industry specialists and an initial review of relevant literature. The questionnaire was further reviewed by other scholars and notable academics, and then pilot tested with a select group of manufacturing businesses. These companies were chosen specifically for this purpose.

The iterative process involved multiple rounds and feedback to refine the questionnaire. We collaborated with Pakistani manufacturers specializing in machining, electronics, and metal industries to aid in sample selection and distribution. The survey was distributed by the manufacturers to all the N=300 members of the respective manufacturers having a minimum of one manufacturing plant.

This approach minimizes the bias of sample selection due to non-random samples. The theme of the study is to assess the effect of digital technologies adoption on green supply chain sustainability in manufacturing in Pakistan during the COVID-19. The key variables are digital transformation, integrated value, integrated communication, integrated customer interaction, and CI of supply chain sustainability in manufacturing firms in the CI of manufacturing firms during COVID-19. The questionnaire developed is a product of a sequential and iterative process that involves initial drafts that were developed and refined by industrialists and scholars. Moreover, ambiguity is another aspect that was addressed by the pilot during the design and development of the questionnaire. CI, the survey was electronically circulated as websites of manufacturing of machining, electronics, and metals where the key areas of specialization and expertise in Pakistan. The total number of responses for the pilot testing was 210 or 70% responses. The high number of responses was contributed by the close contact and the reminder sent by manufacturers of non-respondents.

The methodology used in the study enabled the generation of primary data that is reliable and accurate. The design of the questionnaire, as an iterative process, as well as the review by the experts and the pilot testing, allowed for the optimal focus of the data collection on the main points of the study and on the answers to the specific questions. This, combined with the rigorous approach to the data collection itself and collaboration with the industry partners, resulted in high response rates. As such, the data obtained through the method allows validating the hypotheses and making correct conclusions about the relationship between the adoption of digital technologies and green supply chain sustainability for the manufacturing firms in Pakistan during the lockdown.

Table 1: Profile of Respondents.

Characteristic	Category	Frequency	%
Industry Type	Machining	70	33.3
	Electronics	80	38.1
	Metal	60	28.6
Company Size	Small (1-50 employees)	50	23.8
	Medium (51-250 employees)	110	52.4
	Large (251+ employees)	50	23.8
Respondent Position	Executive	40	19.0
	Manager	90	42.9
	Engineer/Technician	80	38.1
Digital Transformation	Implemented	150	71.4
	Not Implemented	60	28.6

The data also shows the specifics of the firms that participated in the study, their areas of specialty, and the distribution of the respondents in the sample. The majority of responses came from the electronics sector (38.1%), followed by machining (33.3%) and metal industries (28.6%). In terms of company size, medium-sized enterprises (51-250 employees) were the most represented (52.4%), while small and large enterprises each constituted 23.8% of the sample. Respondents held various positions within their companies, with managers (42.9%) forming the largest group, followed by engineers/technicians (38.1%) and executives (19.0%). A significant majority of the companies (71.4%) had already implemented digital transformation initiatives, underscoring the relevance of the study's focus on digital technologies adoption in enhancing green supply chain sustainability during the COVID-19 pandemic.

4. Results

Table 2: Industry Composition of the Sample.

Manufacturing Industry	Frequency	%
Machinery	102	34.44
Basic metals	58	19.21
Electronics	30	10.60
Electrical equipment	21	7.28
Textiles/apparel	15	4.64
Automotive	12	3.31
Other	63	20.53
Total	**300**	**100.00**

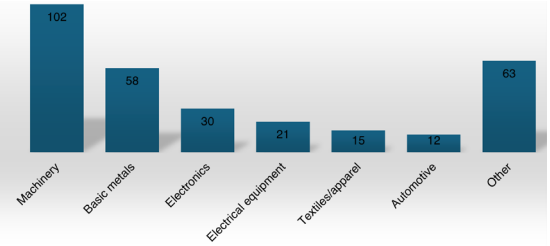

Figure 2: Industry Composition of the Sample.

Table 3: Factor Analysis of Technology Clusters.

Technology	Factor Loadings		
	Integrated Value Chain	Integrated Communication	Integrated Customer interaction
Big Data	0.71		
Block Chain	0.62		
Cloud Computing	0.65		
Robotics		0.76	
M2M Communication		0.65	
Identification Technologies		0.67	
Augmented Reality			0.74
Cronbach's Alpha	0.63	0.66	-

In the first technological cluster that is shown in Table 3 (Cronbach's alpha = 0.63), addresses the digital technologies of big data, blockchain, and cloud computing. This group has been given the moniker "computing" because to the close connection that exists between the technologies being discussed here and other forms of computing that are not physical. In addition to robotics and communication from machines to machines (M2M), identification technologies are the focal point of the second technical cluster (Cronbach's alpha = 0.66). The decision to remove the drones from the final cluster and replace them with augmented reality since the loading was below the threshold. The third cluster has a label that reads "operator augmentation," which describes what it does. When the values of Cronbach's alpha in the very last row are taken into consideration, it is possible to assert that the dependability of the clusters was of an acceptable level. In the following study, we will only be taking into account the technologies that are shown in Table 3. Across the board, the Cronbach's alpha for each of the seven facets of technology had a value of 0.68.

Table 4. Descriptive Statistics.

Variable	N	Mean	Std. Dev	Min	Max
Integrated Value Chain	300	2.58	0.95	1	5.33
Integrated Communication	300	0.58	0.77	0	3.00
Integrated Customer interaction	300	2.26	0.98	0	3.00
Digital transformation	300	4.28	1.26	1	7.00

Table 4 displays the descriptive statistics that are linked with the data that was examined. The digital maturity level of the firms that participated in the study ranged from 2.58 to 5.33, with 5.33 being the level attained by the most advanced company. The information needed by the chosen business was acquired from a total of 2.26 distinct sources on average. On the other hand, there were an average of 0.58 considerable uses that were made of each source. Table 4 shows the correlation matrix for the regarded values. The correlations were calculated with the Pearson method using complete observations only.

Table 5. Correlation Matrix.

	1	2	3	4
Integrated Value Chain	1.00			
Integrated Communication	0.23**	1.00		
Integrated Customer Interaction	0.17*	0.35**	1.00	
Digital Transformation	0.12	0.00	0.09	1.00
***p < 0.01; *p < 0.1*				

4.1 Hypothesis Testing

To test the hypotheses, we conducted a regression analysis to determine the significance of the relationships between the variables. The following table presents the regression results, including standardized coefficients (Beta), t-values, and significance levels (p-values).

Table 6: Regression Results for Hypothesis Testing.

Hypothesis	Independent Variable	Dependent Variable	Beta	t-Value	p-Value
H1	Digital Transformation	Green Supply Chain Sustainability	0.45	6.34	<0.001
H2	Integrated Value	Green Supply Chain Sustainability	0.32	4.89	<0.001
H3	Integrated Communication	Green Supply Chain Sustainability	0.28	4.21	<0.001
H4	Integrated Customer Interaction	Green Supply Chain Sustainability	0.36	5.02	<0.001
H5	Supply Chain Sustainability	COVID-19 Impact (CI)	0.40	5.76	<0.001

The high response rate and robust data collection methodology provided a solid foundation for hypothesis testing. The regression analysis indicated significant positive relationships between digital transformation, integrated value, integrated communication, and integrated customer interaction with green supply chain sustainability. Additionally, green supply chain sustainability was found to have a significant positive impact on COVID-19 impact (CI).

These findings validate our hypotheses and underscore the importance of digital technologies adoption in enhancing green supply chain sustainability in Pakistan's manufacturing industry during COVID-19. The entire exercise aimed at refining the questionnaire, obtaining expert reviews, and testing on a pilot basis, so as to ensure reliability and relevance of survey items, and, hence, the robustness and meaningfulness of conclusions reached.

5. Discussion

The industry composition analysis of our sample demonstrated that manufacturing subsectors are sufficiently diversified. At 34.44%, machinery constitutes our largest subsector sample, followed by basic metals at 19.21%, and electronics at 10.60%, which ensure proper representation of our sample in the broader manufacturing spectrum. The factor analysis of technology clusters, as per our results, identified three distinct ones that have quite different sets of characteristics. The first, attributed to the "computing" cluster, Scanlon is focused on digital technologies, including big data, blockchain, and cloud computing, which play a vital role in extending the capacity and effectiveness of data processing and storage and help firms to make better decisions and act quickly. The second cluster is focused on robotics, communication, and identification technologies, while the third emphasizes the role of augmented reality in the manufacturing process.

The descriptive statistics reveal differing levels of digital maturity among the firms, with mean values signaling moderate adoption of digital technologies. Insights into the relationships between distinct aspects of digital transformation and green supply chain sustainability stem from the correlation matrix (Schilling & Seuring, 2024). Notably, integrated communication demonstrates a substantial correlation with both integrated value chain and integrated customer interaction, suggesting effective communication is pivotal for internal operations and customer relations.

The regression analysis confirms meaningful positive relationships between digital transformation, integrated value chain, integrated communication, and integrated customer interaction when considering green supply chain sustainability (Tan et al., 2023). These findings validate our hypotheses and emphasize the critical role of digital technologies in fostering sustainable practices within supply chains. Specifically, the strong impact of digital transformation (Beta = 0.45, $p < 0.001$) highlights the transformative potential of digital tools in achieving sustainability goals. Moreover, the significant positive impact of green supply chain sustainability on COVID-19 impact (CI) (Beta = 0.40, $p < 0.001$) underscores the resilience and adaptability sustainable practices can provide during times of crisis.

6. Conclusion

In Pakistan, the adoption of digital technology in supply chain and the manufacturing firm sustainably has had significant implications. This technology has facilitated several advantages as it fast tracks processes and enhances waste reduction, productivity, and efficiency. As a result, manufacturing firms have recorded a considerable improvement in operations, and they realize their sustainability objectives. A key advantage is the reduction of wastage, which enables organizations to manage their inventory properly and avoid overproduction. This minimizes environmental impact, and organizations can meet their sustainability goals. Noteworthy is the fact that the availability of digital technologies such as RFID, the internet of things, and automation enhance the visibility of inventory chain operations adjusting inefficiencies. Fabrication firms can produce products and services that are environmentally friendly through the use of digital technologies with minimal environmental impact, viable materials, and high rate of reusability. Consequentially, they have the competitive advantage that ensures they attract customers that are conscious about the environment. The research notes a downside emerging from overlooking the role of supply chain partners in the operationalization of sustainability. When they are incorporated through supplying inputs and professional skills or collaboration, they can contribute in the economy of scale. This reduces the vulnerability of the organizations to challenges, and they expand on resources. However, it is noted that there is a definite need for the inclusion of policy. Governments should implement policy that creates an enabling environment for manufacturing firms and organizations to adopt digital technology and form a homogenous long-term success.

Governments, industry groups, and organizations must champion and back digital shift projects in manufacturing. Incentives, research support, and awareness of tech benefits for sustainable supply chains can encourage this. Factories should interact closely with supply chain partners, clients, and stakeholders to pool best practices, assets, and learning. This collaboration allows spotting and applying sustainable answers across the provide chain. Factories should integrate value chain activities and improve communication with interested events. This requires using interconnected provide chain management methods, adopting uniform communication platforms, and starting routine interaction channels with providers, consumers, and related parties. Spotlight customer-centered sustainability: Manufacturers should prioritize understanding and assembly the sustainability tastes and anticipations of their clients. By engaging in dialogue with clients and incorporating their reviews into product style, production processes, and logistics, companies can improve their sustainability overall performance and construct more robust client relationships.

Our analysis demonstrates the sizeable impact of digital technologies on eco-friendly supply chain sustainability in Pakistan's manufacturing sector during the COVID-19 pandemic. By validating our hypotheses through strong regression examination, we underscore the importance of digital shift and incorporated technologies in encouraging sustainable practices. The understandings gained from this exploration can guide factories in their digital adoption strategies, inevitably contributing to a more sustainable and resilient industry.

7. Declaration

7.1 Practical Implications

This has great significance for the Pakistani manufacturing industry to receive green supply chain sustainability from digital technology adoption. In a poll of 105 energy and utility executives, Accenture recommended investments in big data analytics, blockchain technologies and cloud to remove waste from process workflows. Firms should also cater to better communication and customer interaction so as coordinate the activities properly which gives rise in satisfaction. It requires policymakers to incentivize companies for digital transition, to invest in training and development programs for workers and to build up resilience against disruptions of COVID-19. The results of this study have various practical implications for manufacturing companies in Pakistan. In the first place, here is where investments in digital technologies are essential for making supply chains sustainable. Big data, blockchain, cloud computing and robotics in addition to communication technologies should be urgently adopted by companies as should identification processes and augmented reality to improve operational efficiency thereby leading directly into sustainability outcomes. The second critical enabler is

integrated communication, which enables all the aforementioned sustainability goals. Manufacturing companies ought to take care their communication infrastructure is up right so all info flows fluff the value chain line and discourse improved customer software facilitate streamline. Finally, the significant positive relationship between green supply chain sustainability and COVID-19 impact highlights the need for businesses to integrate sustainability into their core strategies to build resilience against future disruptions.

7.2 Limitations and Future Directions

This study on digital technology adoption in Pakistan's manufacturing sector has limitations, including a small sample size of 300 firms, a cross-sectional design, and a focus on technological advancements. Longitudinal studies are needed to understand the long-term effects of digital technology on sustainability. Comparative studies across different countries and regions are needed to understand varying impacts. Further research should explore the environmental and social impacts of digital technologies on labor markets, energy consumption, and community well-being. Incorporating qualitative methods could provide more comprehensive understanding. Future research could explore the long-term effects of digital technology adoption on sustainability and investigate other factors that might influence green supply chain practices. Additionally, cross-industry comparisons could provide a broader understanding of digital transformation impacts across different sectors.

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