Role of Industry 4.0 Technologies in Enhancing Sustainable Firm Performance and Green Practices

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Abstract: The current state of technological development has transformed everything, so the role of sustainable firm performance, will also increase in the future. For all the societies, it will be very important to find the way of substitution of limited resources. Developed economies have an advantage in its utilization, but it is important to increase their role in developing countries. Technologies such as big data analytics and Internet of Things (IoT) are ready to improve the wave of digital transformation and firms are preparing themselves to gain momentum, in productivity and efficiency, in a green and sustainable manner. The impact of automation in different firms and the study of their correlation, with the firms performance, may have a transformational effect in how firms will adapt to further future innovations. This study discusses the influence of industry 4.0 technologies and green practices, for improving, sustainable company performance. Further, using structural equation modeling (SEM), involving confirmatory factor analysis (CFA) and Exploratory factor analysis (EFA), it is observed that big data analytics do not have a direct significant influence on the company performance, but have a positive significant influence on green practices. While IoT and green practices have a direct positive impact on the performance of the firm.

Keywords: sustainability; industry 4.0; sustainable development; green practices; sustainable firm performance

1 Introduction

The fourth industrial revolution, also known as Industry 4.0, along with its underlying digital transformation, is exponentially progressing. The way individual work and life is being reshaped by the digital revolution and there is an optimism among people, that industry 4.0 may offer several opportunities for sustainable development [1]. The global challenge to deal with more production of goods from scarce and depleting natural resources, is prevailing, since the first industrial revolution in the 18th Century, to meet the constant growth of consumption demands along with reducing adverse social and environmental influences [2] [3]. Constantly, the impact of industry 4.0 on sustainable firm practices and its contribution towards sustainable development concerning social, environmental, and economic aspects is gaining attention [1]. This digital transformation associated with industry 4.0 has captured the attention of governments and manufacturers globally, since 2011, when the term "Industry 4.0" was publicized [4] [5].

Industry 4.0 is defined as, "Industry 4.0 is a collective term for technologies and concepts of value-chain organizations. Within the modular structured smart factories of Industry 4.0, CPS monitor physical process, create a virtual copy of the physical world, and makes decentralized decisions. Over the IoT, CPS communicates and cooperates with each other and humans in real time. Via, the IoS, both internal and cross organizational services are offered and utilized by participants of the value chain" [6]. Industry 4.0 technologies include artificial intelligence, blockchain, robotics, the internet of things, additive manufacturing, simulation, and big data analytics [7] [8]. The technologies of industry 4.0 have the potential to offer enormous competitive and innovation growth, and can enhance the sustainability of the current industrial systems [9] [10]. Industry 4.0 is commonly regarded as the way to enable autonomous systems, by using emerging technologies like big data, IoT, etc. [11]. However, it is accomplished by real-time monitoring, self-organization, optimization along with, the capability of a system to adapt and learn concerning change in the environment [12] [13].

However, sustainability is a broad concept that addresses major aspects of the human world [14], and several authors have reported enablers that smooth the sustainability pathway, through a generalized set of industry 4.0 technologies [15-18]. Also, sustainability is not only associated with environmental sustainability, but also, the preservation of social and economic resources [19] [20]. According to United Nations, sustainability is a "movement for ensuring a better and more sustainable wellbeing for all, including the future generations, which aims to address the everlasting global issues of injustice, inequality, peace, climate change, pollution, and environmental degradation" [1]. Sustainability became a key orientation for current organizations, as a result of the rapid increase in global population, pollution, climate change and depleting natural resources [21]. Hence, sustainability became a major driver of industry 4.0, that can transform traditional firms into smart firms, through the adoption of innovative and digital technologies [22] [23].

Sustainable firm performance and Industry 4.0 are recently emerging organizational and technological trends that pose a major impact on sustainable production and enhanced productivity [24]. These innovative technologies strive for overcoming contemporary challenges such as growth in product customization, volatile demand and markets, global competition, information and intelligence, and a decrease in innovation and life cycle of products [25]. New and sustainable business opportunities are offered by Industry 4.0 along with enhanced production flexibility, reduced time to market, and effective use of resources [26] [27]. However, sustainable performance of the organizations is achieved by constantly supporting all three dimensions of the triple bottom line, such as, the social, economic and environmental dimensions. Industry 4.0 can help businesses support the triple bottom line, and it's being investigated how adopting these technologies can help businesses maintain each dimension of long-term success.

According to a 2019 study by Lin et al., on factors that have an influence on the company performance, the effects of promoting implementation of Industry 4.0 are influenced by other factors such as the characteristics of the industry, shareholding ratio of prominent shareholders, financial leverage and the size of the firm [28]. Industry 4.0 has offered solutions for sustainable firm performance in each and every sector of the economy such as manufacturing, hospitality, tourism, healthcare, education, etc. Industry 4.0 not only provided assistance in improved productivity and meet growing demand but directed towards providing sustainable solutions to achieve sustainable development goals by addressing social, economic, and environmental issues. Furthermore, it deals with some of the crucial requirements to be successful for instance, digital security, transforming work environment, system standardization, following protocols, availability of skilled workers, suitable legal framework adoption, research, and investment [22] [29]. Therefore, this article is aimed at exploring sustainable firm performance, through industry 4.0, in the form of different technologies such as big data analytics, IoT and green practices.

2 Literature Review

According to the Natural Resource-Based View (NRBV) theory, three major strategic capabilities are sustainable development, product stewardship, and pollution prevention. These strategic capabilities correspond to different driving forces concerning the environment, have a distinct competitive advantage, and build upon unique fundamental resources [30]. The NRBV theory emphasizes environmental practices concerning sustainable competitive advantage. The NRBV proposes that "sustainable competitive advantage is achieved when an enterprise's resources which are valuable, rare, inimitable, and non-substitutable are related to specific strategic capabilities, such as pollution prevention, product stewardship, and sustainable development" [31] [32].

The Base of Pyramid (BoP) and the Clean Technology was developed by Hart and Dowell [30] to facilitate the measurement and implementation of the three environmental strategies. It is necessary that employees of the firm must get involved to develop these strategies and it must be emphasized by the organization that concern for the environment is of strategic value. The NRBV approach encourages the development of the organization by focusing on new technologies, using dynamic capacities, and investing in new competencies through the accumulation of non-substitutable and rare resources [32].

Dynamic capability is "the firm's ability to integrate, build, and reconfigure internal and external competencies to address rapidly changing environments" [33]. It is a fundamental objective of Industry 4.0 to sustain and develop the dynamic capabilities of an organization by using IoT, cyber-physical systems, and cognitive computing [34]. Industrial and digitally advanced technologies are being used by firms to gather, transform, and analyze the data generated by using advanced technology and mechanisms [35]. In the digital economy, organizations can make use of their capability by exploiting existing resources or by exploring new methods to do business processes [36].

This digital transformation through industry 4.0 enables a firm to achieve efficiency and become flexible concerning productions and facing challenges. A recent study developed a theoretical framework for green product innovation based on a sustainability-oriented dynamic capability view in a manufacturing firm [37]. In the view of sustainable development, dynamic capability theory is appropriate for studying green product innovation, as firms require to engage in a sustainability-oriented change by transforming their capabilities and creating new ones [37] [38]. Innovation is the key to progress in times of economic crisis and sustainability is the key driver of innovation [39].

In environmental, social, and sustainability management research, stakeholder theory is the foremost approach [37]. The sustainability management and stakeholder theory association require to address the major element which is to define the term stakeholder. This term is defined as "those groups and individuals who can affect or be affected by the actions connected to value creation and trade" [40]. The researchers of corporate sustainability stressed the ecological and social environment and the interdependencies among natural and societal environments with the organization [41]. Similarly, stakeholder theory emphasized the societal embeddedness of firms and their mutual dependency on the societal environment [40]. Hence, both concepts address the issue of societal dependency, environmental possibilities, and obligations of the firm. Therefore, the sustainability management concept stressed on companies to facilitate "an important contribution toward sustainable development of the economy and society" [41].

The supply chain is a process that enables end-to-end business fulfillment by effective information sharing and process integration [42] [43]. Industry 4.0 has brought about further integration between information technology, people who use them, and machinery equipment used to implement the operations [44]. And within the realm of supply chain, the key drivers of 4.0 have been cyber physical systems, Internet of Things, big data analytics, block chain, additive manufacturing and cloud computing systems [45]. They not only enhanced digitalization but also improve system flexibility and agility. It is essential to focus on the procurement, logistics and final fulfillment of the supply chain process. In this aspect, self-driven, smarter GPS enabled and geo-locatable automobiles can enhance the transparency and logistical issues, in the near future. In the business modeling aspect, organizations and managers can utilize fuzzy logic based concepts to forecast and test different approaches in different scenarios to create robust processes in their supply chain [46].

2.1 Industry 4.0 and Firm Performance

According to a 2008 study Wu et al. state that the technological abilities available at a firm have the potential to have an improving effect on the operational decision-making within the organization, as a result of which the organization can benefit by reduction in transaction, logistics cost and also improvement in customer satisfaction [47]. Earlier in a 2004 review of IT and organizational performance, Melville et al. highlight that firm performance is positively affected by inherent human IT capabilities and increased IT infrastructure spending has the potential to improve profitability for the IT adapting organizations [48]. Therefore, following hypotheses were proposed:

H1: *Adoption of big data analytics technology significantly improves overall firm performance.*

H2: *Adoption of Internet of Things (IoT) significantly improves overall firm performance.*

2.2 Green Practices and Firm Performance

The green and lean approach aim to firstly make the supply chain process more environmentally conscious and sustainable which then supports the aspect of lean which focuses on elimination of anything that adds no value to the successful completion of the process while maintaining high levels of productivity [49]. Together they create a very harmonious combination and make very efficient and robust systems, hence, reducing costs of operations. Clean and smart technologies such as blockchain and cloud based computing perfectly align with the principles of green and lean as they only require computer interface and connectivity to run the processes smoothly without taking up much space or fuel. With regard to individual supply chains, the beneficial effect of industry 4.0 and its enabling processes can be implemented using further development of process integrity, automation, digitization and optimization which in turn creates enhanced analytical capabilities and, improved productivity and performance on the fundamental supply chain level [43]. Further, in the future of supply chain Ivanov & Dolgui highlight that supply chain disruption risk analysis will be more dependent on predictive analytics in the era of industry 4.0 [50]. Hence, the following hypothesis is framed:

H3: *Implementing green practices significantly improves overall firm performance.*

2.3 Industry 4.0 and Green Practices

With the advent of industry 4.0 we have at our disposal many waste reducing solutions such as cyber physic systems, Internet of Things, big data, blockchain etc. that completely run on network and significantly less electricity which can also be sourced through renewable energy [51]. The rate of carbon emission had dramatically increased since the heavy industrialization and mechanization of manufacturing, production and agriculture industries. The previous industrial revolutions heavily relied on the availability of nonrenewable energy resources to run the machinery and emitted carbon and various other pollutants as a result. The sophisticated digital solutions provided by the intelligent technologies in the ongoing era of industry 4.0 can greatly influence these processes to run efficiently without over utilization of resources and move to cleaner resources. Bai et al. recognize that it is difficult to evaluate the impact of industry 4.0 in all aspects of the production and manufacturing business yet it can help to reach one of the United Nations Sustainable Development Goals of "Climate Action" by enabling the monitoring and gradual reduction in the unit emission of carbon across the industries [52]. Blockchain technology is also being used in the process of actual monitoring and maintenance of transparent carbon trading in the European Union and other similar models across the world. Countries like Japan, South Korea, Germany, Turkey have promised big targets in reducing their total carbon emissions by 2030 in the Paris accords for Environmental sustainability by utilizing automation, innovation and smart technologies in every possible avenue for developing the sustainability of the industry. Therefore, the study proposed following hypotheses-

H4: *Adoption of big data analytics technology significantly improves overall green practices.*

H5: *Adoption of Internet of Things (IoT) significantly improves green practices.*

The above five hypotheses are considered to formulate the below conceptual framework for the purpose of this study:

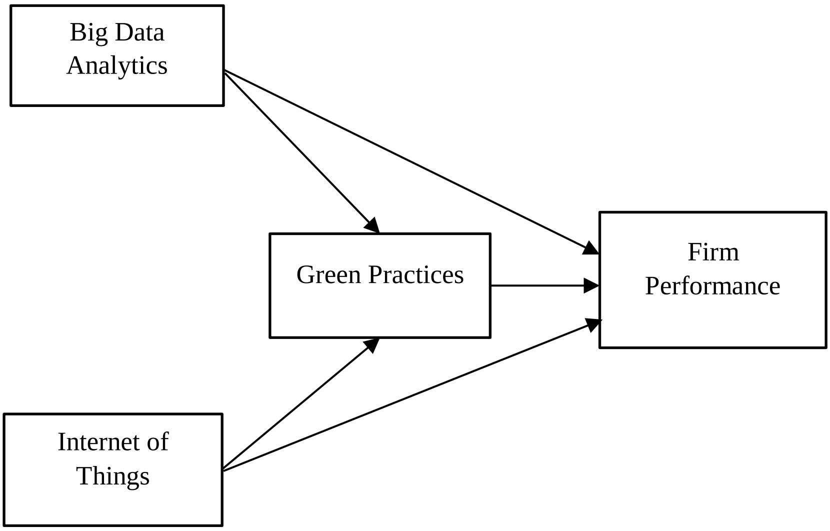

Figure 1
Conceptual framework of the study

3 Methods

3.1 Sample and Procedure

The study aims to explore the role of industry 4.0 and green practices implementation in improving environmental firm performance, and to analyze the influence of industry 4.0 in improving green practices. Finally, to verify whether green practices can affect environmental firm performance. To establish the relationship between above-mentioned variables, data was collected through an online questionnaire. The employees working in different small and medium size enterprises in India were the target population of this study. For data collection from the target population, a well-structured questionnaire was designed and distributed. In the beginning of the questionnaire, an introduction message was provided that detailed the purpose of the research. Next, the linear snowball sampling method was employed to collect the data from target population. Online platform was used to circulate the questionnaire to the employees. Around 350 requests for participation in the survey were issued to employees, and total valid responses without any missing value were 224 which are used for the data analysis. The response rate of the data sampling was 78.4% regarded a reasonable response rate [53]. Around 350 requests for participation in the survey were distributed to employees, and 224 answers were valid with no missing values and included for analysis, with a response rate of about 78.4%, which is considered reasonable for the analysis [53].

Table 1 presents the demographic profile of the participants.

Table 1
Demographic profile of respondents

Traits	Item	Count
Gender	Male	123
	Female	95
	Prefer not to say	6
Work tenure	Less than one year	66
	Between one year to five years	103
	Between five to ten years	43
	More than ten years	12
Age	18–25	57
	26–35	112
	36–45	41
	46–55	14
	Above 55	0
Company's sector	Financial and trade	91
	Tourism	35
	Hospitality	29
	Transportation	32
	Health care	14
	Other	23

3.2 Measures

The questionnaire was divided into two sections, the first of which was intended to collect information on the respondents' sociodemographic characteristics. The following section used questions with five-point Likert-scale which had values ranging from 1 to 5, equating to strongly disagree to strongly agree. The following section used five-point Likert-scale questions, with values ranging from 1 to 5, equating to strongly disagree to strongly agree. The latent variables, such as industry 4.0, green practices, and overall company performance, were expected to be measured using these Likert-scale-based questions. The construct questionnaire items were taken from studies done by various authors, such as Imran [54], for industry 4.0 constructs, while Perramon et al. [55] and Kristoffersen et al. [56] for green practices and firm performance, respectively, because they were the most appropriate for the study the researchers wished to perform. Table 2 shows the descriptive statistics of the variables under investigation, as well as the correlation between them.

Table 2
Correlation and descriptive statistics

Variables	Mean	1	2	3	4
BD	4.02	-			
IoT	4.32	0.446**	-		
Green practices	4.35	0.565**	0.492**	-	
Firm performance	4.25	0.360**	0.445**	0.523**	-

Note: ** Correlation is significant at the 0.01 level (two tailed).

3.3 Common Method Bias

It is advised to examine the common method bias before conducting the exploratory and confirmatory factor analysis. In this, the variance is "attributable to the method of measurement instead of the measures that represent the constructs" [57]. If the data have common method bias, then the validity of the results becomes questionable [58]. As a result, the researchers used Herman's one-factor test to investigate the possibility of common method bias. To achieve the requirements, all items of the questionnaire were loaded into an exploratory factor analysis with one component extracted and no rotated factor solution. The findings of Herman's one-factor test reported that one-factor solution only explained 37.56% of explained variance. To fulfill the requirements, Herman's one factor test suggested maximum variance of 50% [59] and our results are less than the maximum considered threshold percentage. This means that the study's common method variance is unlikely to be threatened, allowing researcher for further investigation.

3.4 Reliability Analysis

The reliability test was performed prior to examining the results and hypotheses. The Kaiser-Mayer-Olkin (KMO) test and Bartlett's sphericity test (BTS) were used to evaluate the questionnaire's appropriateness. If the value of KMO test is more than 0.6 and BTS is significant with p value less than 0.05 then the dataset is suitable for factor analysis [60]. The KMO value in our investigation was found to be 0.885, indicating that the data is accurate. Additionally, our results revealed that the factors are correlated and appropriate for investigation as using BTS p-value less than 0.05 indicates that the dataset under consideration is not an identity matrix.

Furthermore, the overall Cronbach's alpha of the entire questionnaire is 0.892 which shows high reliability and is acceptable for an exploratory study. However, instead of performing a single reliability test on the entire instrument, some researchers recommend examining the reliabilities of each construct independently. As a result, each factor was subjected to reliability testing, with the values of Cronbach's alpha ranging from 0.765 to 0.860 (Table 3). Cronbach's alpha of 0 to 1 with $r = 0.7$ or higher is regarded good, this result shows that the factors are fairly reliable [61].

The second validity measurement test is composite reliability (CR). CR was used to examine the measure of internal consistency, according to Hair et al. [60], for each construct, a CR threshold of greater than 0.7 is satisfactory [62]. Internal consistency reliability (ICR) and convergent validity are shown in Table 3.

Table 3
Reliability test and Composite Reliability (CR)

Variables	Items	Item loadings	CR	Cronbach alpha
Big data analytics (BD)	BD1	0.799	0.86	.850
	BD2	0.830		
	BD3	0.813		
	BD4	0.675		
Inter of Things (IoT)	IoT1	0.581	0.80	.765
	IoT2	0.694		
	IoT3	0.589		
	IoT4	0.782		
	IoT5	0.681		
Green Practices (GP)	GP1	0.665	0.82	.860
	GP2	0.758		
	GP3	0.651		
	GP4	0.668		
	GP5	0.752		
Firm Performance (FP)	FP1	0.775	0.81	.782
	FP2	0.855		
	FP3	0.660		

3.5 Model Fit Indices

Hair et al. (2010) state that analyzing the model's goodness of fit indices is necessary before drawing conclusions [63]. The “model's chi-square (X2), degree of freedom of the model (df), the Tucker–Lewis index (TLI), comparative fit index (CFI), goodness of fit indices (GFI), and the root mean square error of approximation (RMSEA)” are some of the common indices used for this purpose. The acceptable limitations of these indices must be met for a decent model fit measure, X2/df < 5, RMSEA < 0.09, TLI close to 1, GFI > 0.9, and CFI > 0.9 are suggested limits or threshold values [64]. As a result, it's critical to assess the model's goodness of fit before moving on to the final analysis.

The results in Table 4 show that each construct is well-fit. The model fit will be used to test the hypotheses in this investigation.

Table 4
Model fit indices

Fit Index	X^2/df	CFI	TLI	GFI	RMSEA
Value	1.699*	0.947	0.936	0.908	0.056

Note: *p < 0.05

4 Results

4.1 Data Analysis

The researchers employed structural equation modeling (SEM) with the AMOS 22 program to test their hypothesis. SEM was used to determine the association between independent and dependent variables, and a covariance matrix was used. It is also employed by researchers to identify the influence and weight of independent factors on dependent one. Also, to conduct regression analysis and confirmatory factor analysis (CFA) simultaneously gives SEM an advantage over other modern techniques [65].

The dataset was entered into the SPSS V25 program, prepared and coded according to the dimensions. Then we performed validity and reliability tests and the variables' mean score based on the responses was determined. After that, the data was imported into AMOS v22, where the SEM was carried out.

4.2 Hypothesis Test

According to the findings provided by SEM analysis presented in Table 5 shows that big data analytics do not pose significant impact on firm performance ($\beta = 0.083$, $p > 0.001$), but positively influence green practices ($\beta = 0.304$, $p < 0.001$) signifying that the adoption of big data analytics technology will provide improved execution of green practices in an organization. In addition, the path analysis revealed that IoT is positively associated with both environmental firm performance ($\beta = 0.224$, $p < 0.001$) and green practices ($\beta = 0.428$, $p < 0.001$) indicating that implementation of IoT technology in an organization positively enhance the implementation of green practices and increase environmental firm performance. Furthermore, green practices also pose a significant direct influence on firm performance (($\beta = 0.406$, $p < 0.001$) which indicates implementing green practices in an organization will enhance overall environmental firm performance. These results have proved hypotheses H2, H3, H4, H5, but rejects H1.

Table 5
Hypothesis test

Structural Path	Beta weights	SE	CR	P value	Remark
BD->FP	0.083	0.044	1.320	0.187	H1 Rejected
IoT->FP	0.224	0.059	3.403	***	H2 Accepted
GP->FP	0.406	0.054	5.983	***	H3 Accepted
BD->GP	0.304	0.051	5.206	***	H4 Accepted
IoT->GP	0.428	0.066	7.333	***	H5 Accepted

Note: $p < 0.001$

5 Discussion

The need for innovation combined with creativity has expanded the applications of Industry 4.0 technologies across all the industries existing in modern times in some or other ways. The major breakthroughs have been applied at the quickest pace in automation, production, quality assurance, process integration and sustainable manufacturing to name a few processes. Evidently, it can be proposed that in the post Covid-19 pandemic scenario, there will be extensive utilization of revolutionary technologies in the supply chain, tourism, healthcare and agriculture sectors as these industries were the worst affected during the Covid-19 pandemic. These sectors of the economic ecosystem weren't prepared for such unforeseen conditions and were heavily reliant on manual or inflexible operational systems. This caused unimaginable disruption and chaos during the sudden and lengthy lockdowns, due to the Covid-19 pandemic, enforced around the world. This highlights the vulnerability and unsustainability of the sectors by not only causing rampant unemployment but also wastage of precious resources and inequality.

Our findings suggest that incorporating industry 4.0 technologies will enhance the implementation of green practices, which further enhance the environmental firm performance. Hence, firms and managers must incline towards incorporation of sustainable and green practices in small and medium size enterprises. In the context of developing and emerging economies, the role of government policies, in terms of encouraging programs, subsidies to automate industries, plays a major role in driving sustainable firm performance. Top Management's commitment and participation in enforcing the sustainability philosophy across its processes is also considered as a driving force for the implementation of sustainable process across all geographies [66]. With great awareness among the general population there is also societal pressure and regulation based on public concerns for the environment, enforce actions that are not harmful to the ecosystem or the population of the place. The sustainable production processes utilize systems that operate via the Internet of Things and artificial intelligence to schedule and fix machine loadings, route determination for vehicles, production flow controls and manage timely deliveries and monitor vehicle navigation [67]. The challenges arise for huge companies from sustainable development policies that hinder the efficiency of the processes and the actual production time of the products from manufacturing resources [68-70]. These challenges can be potentially mitigated through by adapting innovative solutions in combination with lean and green production process and practices for greater resource management to improve on firm performance. Apart from the usual, IoT, big data and cloud driven platforms, 3-dimentional and augmented reality, virtual reality has been gaining leverage to experience the senses of being in a different place while being at home, in the context of firm performance this may enhance the remote working experience or work from home requirements for employees after the Covid-19 pandemic [71-76]. Big data and blockchain enable the users to have automated data collection, verification, complete data safety and transparency which are important for keep safe of sensitive firm data [77-80].

Conclusions

It is evident that there is an ever-growing demand in the global market for sustainable solutions for waste reduction, circular economy and cleaner manufacturing, to enhance firms performance and sustainably. This is due to the pressures that the heavy industrialization of the economy has created on the Earth and the related limited resources. Digitalization, automation and precision technologies in manufacturing, supply chain and production adopted by developing economies, can yield a huge competitive advantage, in the global market and encourage implementation of Industry 4.0, in local firms, to improve their performance. There are still many barriers to the adoption of advanced technologies for weaker economies, start-ups and small and medium size enterprises, for example, huge costs of implementation and maintenance, lack of connectivity infrastructure, unavailability of trained and skilled employees, automation causing unemployment and so on. Despite many such challenges and unforeseen circumstances, such as, the Covid-19 pandemic, there will be greater adoption and transformations, ultimately, leading towards a more sustainable future.

Therefore, considering various limitations, in terms of data availability and other factors that affect companies performance, the conclusions of this study imply that, merely implementing big data analytics on its own, may not have the expected positive impact, directly on a firms performance. Alternatively, the results indicate that, the adoption of big data, enable the implementation of green practices in the processes of the firm. Meanwhile, embracing IoT can significantly enhance the implementation of green practices and improve performance.

Conflict of Interest

The authors declare no conflict of interest.

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