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Impact of Technologically Vigilant Leadership on Smart Sustainable Circular Supply Chain Management

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Abstract

The main aim of this study is to explore how technologically vigilant leadership (TVL) impacts on smart sustainable circular supply chain management (SSCSCM) in the context of Industry 6.0. This is accomplished by analyzing the mediating effect of the digital environment management accounting system (DEMA) in the relationship between TVL and SSCSCM. This research evaluated the proposed model using two distinct statistical methods within the framework of structural equation modelling, which facilitated the assessment of both linear and non-linear correlations among the constructs. The data was obtained from a sample of respondents employed in small and medium enterprises. Linear relationships were analyzed using SmartPLS, whereas non-linear relationships were examined with WarpPLS. In both instances, the influence of TVL on SSCSCM was significant and positive, as demonstrated by CB-SEM in SmartPLS 4.1.0.9 and PLS-SEM in WarpPLS 7.0. Furthermore, DEMA partially mediated the relationship between TVL and SSCSCM. The current investigation is one of the few that provides conclusive evidence on the impact of TVL on SSCSCM. Also, it offers new insights by highlighting that DEMA partially mediates the relationship between TVL and SSCSCM. These profound insights would provide guidance for practitioners and policymakers in developing improved TVL mechanisms to leverage the advantages of DEMA and thereby strengthen SSCSCM.

Keywords:

Circular Economy;
Environmental Management Accounting;
Industry 6.0;
Smart Supply Chain;
Vigilant Leadership.

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1- Introduction

Sustainability imperatives and transformative technological advancements have necessitated responsible consumption and enhanced production from the industrial sector [1]. According to recent research [2], effective supply chain management is essential for the survival of industries. The environment can be considerably impacted by the extensive supply chain, which generates waste and produces greenhouse gas emissions [3]. The combined objectives of sustainable economic growth and environmental preservation have made the reduction of energy consumption intensity in business a critical focus of global strategies. The concept of circular economy has been incorporated into the supply chains of industries worldwide as a result of the ever-increasing levels of pollution and refuse creation [4]. The integration of circular economy principles into supply chain management is a critical factor in the acceleration of the transition to a circular economy and the realization of its sustainability potential [5]. Circular supply chain management has been considered as the innovative application of circular principles to supply chain management and the supply chain environment, with the goal of achieving zero waste and surpassing conventional supply chain sustainability models in the pursuit of supply chain circularity [6]. Based on the standpoint of Zhang et al. [7], the competitive advantage of a company can be significantly influenced by the digital transformation of supply chain management. In this regard, smart supply chain practices introduce a novel perspective to transform conventional supply chain processes in both developed and developing countries.

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One potential solution is the implementation of smart supply chain management, which can enhance integration and reduce costs [8]. Taking advantage of circular supply chain management and smart supply chain practices, smart circular supply chain management is proposed. A smart circular supply chain is a system that is informationally connected and utilizes smart technologies to achieve supply chain digitization and integration. This system also enhances the efficiency of information dissemination and resource management capabilities, thereby facilitating optimal operations. This system encourages recycling practices and prevents the exhaustion of natural resources in the supply chain sustainability domain. In the context of Industry 4.0, numerous academic notes have provided a deeper understanding of circular supply chains (i.e., [9-12]). Additionally, some studies have investigated the supply chain in the context of Industry 5.0 ([13-15]). The substantial transformation in the manner in which businesses conduct business is reflected in the development of artificial intelligence in supply chain management throughout Industry 4.0, 5.0, and 6.0 [16]. High implementation costs, concerns regarding data security, and the necessity of acquiring new skills are all obstacles to the successful integration of artificial intelligence into Industry 4.0 supply chains.

Industry 5.0, however in its nascent developmental phase [17], has the capacity to transform our methodologies of production and consumption [18]. Meanwhile, it is anticipated that artificial intelligence systems in Industry 6.0 will enable circular economies, reduce waste, and enhance resource reutilization on a large scale. According to Singh et al. [19], researchers are beginning to consider Industry 6.0, a novel concept, as an advancement beyond Industry 5.0. As stated by Kumari and Tyagi [20], the emergence of Industry 6.0, defined by the incorporation of advanced technologies like artificial intelligence, blockchain, and the Internet of Things, has ushered in a novel epoch of connectivity and collaboration. A smart sustainable circular supply chain management (SSCSCM) amalgamates Industry 6.0 and circular economy principles inside the supply chain to fulfill Sustainable Development Goals. As such, effective leadership will play an important role in enabling organizations to succeed in SSCSCM. This phase, while promising, presents obstacles in the form of the seamless integration of autonomous systems, the resolution of ethical concerns, and the maintenance of governance frameworks that enable the responsible implementation of artificial intelligence across interconnected supply chains [16]. Organizations must reimagine and redesign their supply chains, including sourcing, operations, logistics, returns, and disposal, in order to adopt and implement circular economy [21]. The incorporation of circular thinking in supply chain management, also known as circular supply chain management, includes closed-loop supply chains, remanufacturing, recycling, reverse logistics, industrial symbiosis, and other practices that are designed to achieve a zero-waste vision [22]. Regrettably, the circular supply chain in the context of Industry 6.0 is only covered in a small number of academic works.

Environmental management is essential for the advancement of supply chain management and remanufacturing, as it reduces waste, optimizes resource utilization, and increases the lifespan of products [23]. The risk exposure of circular supply chains could be mitigated through the implementation of emerging analytical and digital tools and technologies, which could facilitate the transition to a circular economy [24]. In this regard, organizations have increasingly relied on digital environmental management accounting (DEMA) to facilitate their eco-efficiency decisions. By suppressing opportunistic behaviors in transaction relationships, the DEMA enhances operational transparency and traceability, thereby reducing agency costs and improving governance. The transparency allows stakeholders—investors, regulators, and consumers—to evaluate the company's ethical practices and sustainability promises, so cultivating trust and confidence in its governance. Through the utilization of traceability, organizations can recognize and alleviate hazards including regulatory non-compliance and market demand.

More remarkably, the implementation of emerging technologies requires disruptive changes in traditional operational methods, systems and even organizational cultures, thus posing significant challenges for companies [25]. Therefore, the key to bolstering SSCSCM implementation lies in the establishment of an enabling mechanism for change that can effectively deploy and integrate this technology to unlock its full potential. Furthermore, the absence of a facilitating diffusion mechanism may hinder the realization of the advantages associated with the technological adoption throughout supply chains [26]. Supply chain managers necessitate expertise in sustainability, strategic thinking, analytical decision-making, collaboration and stakeholder engagement, risk management to proficiently execute circular economy principles in smart sustainable supply chain management. Among them, technology vigilance skills warrant significantly greater attention. Vigilant leaders, who prioritize predicting possible issues and obstacles, will significantly reduce followers' complacency and foster a sense of duty to implement constructive changes [27]. In line with its findings, technologically vigilant leadership (TVL) is characterized by leaders who raise awareness of recent technological advancements, assess which of these pose threats or opportunities, manage their effects on products, services, and the internal organization, and concurrently guide employees during periods of uncertainty while motivating them to adopt precautionary measures to alleviate those threats. It is contended that although technologies are available to companies, competences must be cultivated not only within those companies but also throughout their supply chains for these technologies to be fully utilized [28]. Supply chain managers must continuously enhance their competency profiles to address global and industry issues and opportunities across all sectors. This is pertinent to certain contemporary issues, including the low-carbon economy [29] and supply chain resilience [30].

The combined study of vigilant leadership, sustainable circular supply chain, Industry 6.0, and environmental management accounting in small and medium enterprises (SMEs) in the context of developing countries has been the subject of limited research until recently. This is primarily due to the emergence of these relationships in recent years. In light of this, it is imperative to establish more comprehensive management models and policies to optimize and enhance the efficiency of the SSCSCM of SMEs. The primary objective of this investigation is to explore the potential role of TVL in improving SSCSCM and the role of DEMA in this relationship. This research analyzes the research questions as follows.

- *RQ1. What is the effect that TVL induces on SSCSCM?*
- *RQ2. Does DEMA mediate the relationship between TVL and SSCSCM?*

The present study addressed specific gaps that were identified in the examination of the overall results and key observations, thereby making contributions to both the academic and practitioner communities. By addressing the gaps in the literature on SSCSCM in developing countries, the current research findings broaden the existing boundaries of knowledge. In developed countries, sustainable supply chain management techniques are becoming prevalent, whereas developing countries exhibit a deficiency in sustainable practices due to many constraints, including knowledge, resources, support, and guidance [31]. In the current period of swift globalization and technological progress, supply chain management has become an essential element for improving corporate competitiveness and facilitating sustainable growth [32]. The current research is a pioneering study that examines the interconnection between TVL and SSCSCM in SMEs in developing countries. Leadership has been a substantial examination, focusing on it as a process and a collection of characteristics linked to successful individuals [33]. Scholars have been studying the function of leadership within supply chains as organizations have become more interconnected through intra- and inter-organizational supply chains [34]. In doing so, the obtained findings in this research enrich the body of literature focusing on the crucial competences of supply chain managers. The perceptions of top management on environmental challenges affect the opportunities for and implementation of voluntary environmental strategies [35]. TVL allows supply chain managers to view the overarching context from a temporal standpoint and discern fundamental issues that could result in future failures in the management of smart sustainable circular supply chains.

As such, the TVL is crucial for the expansion and reinforcement of SSCSCM. It also addressed a research gap in previous studies by providing empirical evidence on the mediating role of DEMA in the relationship between TVL and SSCSCM. The domain of environmental management accounting has consistently garnered interest in recent years [36]. With the increasing frequency and speed of information transmission across the supply chain network, supply chain managers can share enduring behavioral data regarding products and provide virtually instantaneous answers through innovative processing methods. The exchange of information among supply chain partners [37] and forecasting methods that yield reliable outcomes while minimizing waste production are recognized as essential elements for effective circular supply chain management [38]. The implementation of forthcoming analytical and digital tools and technology may mitigate the risk exposure of circular supply chains and facilitate a seamless transition to a circular economy [24]. Nevertheless, they frequently lack the necessary tools and resources to execute these policies effectively. The use of environmental management accounting provides enhanced visibility of environmental information to numerous stakeholders [39], and this visibility significantly positively influences environmental practices [40]. Increased environmental concerns have compelled organizations to comply with regulatory requirements, creating a demand for internal accounting systems that support managerial decision-making [41]. DEMA enables practitioners and policymakers to establish strategies and policies that assist enterprises in implementing the incentives of Industry 6.0, resulting in significant enhancements in their processes and the industry.

The implementation of circular supply chain management in SMEs has evolved from a mere trend to an essential strategic imperative in the contemporary, rapidly changing business landscape. Given the complexity of supply chain networks, SMEs encounter numerous challenges that require their involvement in circular supply chain management [42]. Previous research identified challenges including resource limitations, legislative restrictions, and heightened consumer demands for environmentally sustainable products [43]. SMEs must have a comprehensive understanding of the interrelation among different essential success factors in SSCSCM to make educated supply chain decisions successfully within this intricate environment. As such, this research evaluated the proposed model using two distinct statistical methods within the framework of structural equation modeling, which facilitated the assessment of both linear and non-linear correlations among the constructs. In doing so, the obtained findings will help SMEs to formulate strategic operating strategies and allocate resources effectively. Refrain from excessively dedicating resources to a certain task, since this would render it redundant and hinder SMEs from enhancing their operational performance.

The present investigation is organized as follows. Section 2 provides a concise overview of conceptual elements and their theoretical foundations. Section 3 of the study delineates the formulation of research hypotheses and the construction of a research model. Additionally, Section 4 provides a detailed overview of the research methodology, while Section 5 presents the outcomes and implications derived from the study. The sixth section of this work delineates the conclusion as well as noteworthy insights into future research.

2- Literature Review

Stakeholder theory: Stakeholder theory offers a conceptual structure for comprehending the wider social, environmental, and economic impacts of operational activities in organization [44]. With the advent of digital technology, key stakeholders have gained more authority to exert influence on organizations, either directly or indirectly, to advocate for digitalization [45]. Stakeholder pressure has intensified for firms to engage in sustainable development

[46]. Sustainability pressures and radical technological development have mandated responsible consumption and value-added production from the industrial community [1]. Circular economy models are intricate and necessitate collaboration and engagement from stakeholders, particularly the active participation of supply chain management [47]. Thus, stakeholder theory can elucidate the reasons behind how TVL and DEMA will improve and enhance SSCSCM.

Smart sustainable circular supply chain management: In the context of Industry 4.0, numerous academic notes have provided a deeper understanding of circular supply chains (i.e., [9-12]). High implementation costs, concerns regarding data security, and the necessity of acquiring new skills are all obstacles to the successful integration of artificial intelligence into Industry 4.0 supply chains. Some studies have investigated the supply chain in the context of Industry 5.0 ([13-15]). Industry 5.0, however in its nascent developmental phase [17], has the capacity to transform our methodologies of production and consumption [18]. Meanwhile, it is anticipated that artificial intelligence systems in Industry 6.0 will enable circular economies, reduce waste, and enhance resource reutilization on a large scale [16]. Industry 6.0 anticipates intelligent, fully integrated systems that reduce human intervention by amalgamating artificial intelligence, human-robot collaboration, cloud computing, big data analytics, and quantum computing [48]. Sustainable supply chain management refers to the collaboration of organizations to deliver environmental and social advantages either inside an individual organization or across the entire supply chain [49]. Managing a circular supply chain aims to shut material and energy loops, minimize resource inputs and waste, thus improving operational efficiency and securing a competitive advantage [50]. The incorporation of Industry 6.0 technologies into circular supply chain management has represented a substantial advancement in sustainable operations in recent years. A SSCSCM amalgamates Industry 6.0 and circular economy principles inside the supply chain to fulfill Sustainable Development Goals. By promoting the use of circular economic ideas, Industry 6.0 enhances environmental sustainability while providing businesses with avenues for innovation, competitive edge, and enduring viability.

Digital environmental management accounting: Environmental management accounting was developed to assist companies in identifying, measuring, and managing the costs related to natural resource utilization, waste production, and pollutant emissions, thereby enhancing organizational transparency regarding environmental expenses, improving resource efficiency, minimizing waste, and reducing operational costs [51]. In this research, DEMA can be understood as the integration of digital technologies of Industry 6.0 into environmental management accounting system. Environmental management accounting has significantly expanded as an accounting and administrative instrument [52]. Organizations have progressively adopted environmental management accounting, acknowledging its ability to reveal hidden environmental costs and improve eco-efficiency [53]. In the Iranian manufacturing sector, environmental management accounting facilitated enhanced resource control [54]. They further indicated that firms integrating environmental management accounting with a strategic emphasis on sustainability improved their environmental performance while simultaneously augmenting their market competitiveness. Environmental management accounting enables companies to capitalize on opportunities for enhancing their operational processes, as the comprehensive understanding of environmental impacts offers a thorough perspective and aids in the execution of strategies that optimize resource utilization and reduce waste [55]. Consequently, organizations that use environmental management accounting techniques can distinguish themselves in the marketplace through an ecological strategy, contributing to the organization's long-term performance [56]. Another study examined the moderating effect of digitally facilitated environmental management accounting on the link between eco-efficiency and business sustainability performance [57].

Technologically vigilant leadership: The findings of Zheng et al. [58] indicate that human capital has a favorable impact on digital maturity and supply chain resilience. In his research, Bag [59] examines the moderating influence of supply chain managers perceived professional level on restorative supply chain practices and stakeholder participation. Wahab et al. [60] analyze and identify prevalent patterns in employment needs within the logistics and supply chain sectors by examining job posting content in Malaysia. Modgil et al. [61] endeavor to identify and cultivate the appropriate competencies for supply chain professionals within the framework of Industry 5.0. In the same vein, Tran et al. [62] delineate the required supply chain managerial competencies that logistics managers must possess to augment their individual effectiveness in the contemporary day. In recent years, the diffusion of technology, globalization, and the Internet revolution have expedited the expansion of online transactions and transformed company operational systems [60]. Vigilant leadership positively influences employees' preventive focus and fosters a range of proactive behaviors, such as problem prevention, strategic scanning, feedback inquiry, surpassing the impact of transformative leadership. Vigilant leadership is a leadership style that empowers leaders to adeptly manage complex situations and make educated judgments promptly. In line with the academic findings, TVL is characterized by leaders who raise awareness of recent technological advancements, assess which of these pose threats or opportunities, manage their effects on products, services, and the internal organization, and concurrently guide employees during periods of uncertainty while motivating them to adopt precautionary measures to alleviate those threats. It is confirmed that supply chain transformational leadership is a pivotal catalyst for supply chain innovation. Transformational leadership profoundly influences green supply chain management techniques and sustainable corporate performance [63]. The correlation between transactional leadership and green supply chain management is relatively weak [64]. The implementation of blockchain technology improves both the proactive and reactive aspects of supply chain resilience, with these impacts mediated by transformational supply chain leadership [65].

3- Hypothesis Development

Supply chains must be more intelligent to address the previously mentioned challenges [66], deliver sustainable outcomes [67], and minimize human-machine interaction to promote the adoption of sustainability practices that support circular economy principles [68]. A smart supply chain enables stakeholders to optimize and streamline processes, aiming to reduce production costs and company expenses. Gao et al. [27] asserted that vigilant leaders, who prioritize predicting possible issues and obstacles, will significantly reduce followers' complacency and foster a sense of duty to implement constructive changes. TVL allows SMEs to evaluate the prospective future results of their current activities and is affected by those potential outcomes. TVL allows executives to view the overarching context from a temporal standpoint and discern fundamental issues that could result in future failures in the management of smart sustainable circular supply chains. Technologically viligant leaders with a strong strategic vision are essential for advancing innovation in sustainable practices, promoting the implementation of digital technology, sustainable sourcing, and circular economy concepts. In doing so, proficient leaders are adept in recognizing and alleviating sustainability-related risks, including resource scarcity and regulatory alterations, thereby enhancing sustainability performance. Furthermore, the innovative incorporation of digital technology by leaders can markedly improve transparency and sustainability in supply chain operations.These arguments aid in the formulation and development of the following hypothesis.

- *Hypothesis 1 (H1). TVL is likely to significantly and positively influence SSCSCM.*

The difficulty for leaders is to effectively manage substantial volumes of conventional information while enhancing their capacity for focused attention. Vigilant leadership is a leadership style that empowers leaders to adeptly manage complex situations and make educated judgments promptly. In vigilant organizations, leadership focus is utilized to enhance agility and competitive advantage, whereas in vulnerable organizations, misallocated attention results in blind spots, shortsightedness, and delayed responses. The vigilant leaders prioritize the long-term sustainability of their teams and motivate their staff to gather peripheral information and anticipate potential issues prior to their emergence [27]. Environmental management accounting pertains to environmental information that has ecological implications and enhances the sustainability performance of an organization [18]. Executives with an optimistic perspective on the implementation of environmental practices are more inclined to enhance their companies' engagement in environmental management [19]. Recent years have witnessed exponential technological advancement, leading to significant digital transformation activities within companies [69]. Digitalization has substantial prospects for process enhancement by enabling a corporation to reduce resource consumption through the implementation of information and communication technology tools [70]. When companies implement innovative systems, they enhance their ability to improve their environmental management accounting systems; hence, they can make more effective decisions, ultimately resulting in improved financial performance [57]. These arguments aid in the formulation and development of the following hypothesis.

- *Hypothesis 2 (H2). TVL is likely to significantly and positively influence DEMA.*

The effectiveness of sustainable supply chains is contingent upon the circular economy proficiency of organizations, as evidenced by pollution levels and resource utilization efficiency within supply chain operations [22]. The deployment of environmental management accounting has a markedly positive impact on corporate performance, and that environmental management accounting fosters innovation in processes, hence enhancing overall company performance. From the standpoint of managerial accounting, environmental management accounting is a synthesis of cost and financial accounting techniques aimed at reducing environmental impacts, managing risks, and lowering costs [71]. Environmental management accounting, as a systematic technique, entails the identification, measurement, and management of environmental costs and benefits linked to economic activities, hence facilitating more effective and transparent resource management [72]. Environmental management accounting enhances waste management efficiency, hence immediately diminishing the organization's environmental impact [56]. These arguments aid in the formulation and development of the following hypothesis.

- *Hypothesis 3 (H3). DEMA is likely to significantly and positively influence SSCSCM.*

Digitalization is as essential as circular development for firms' enduring advantages in attaining sustainability. The shift to Industry 6.0 has catalyzed the redefinition of supply chain management towards smarter, more sustainable, and circular approaches. TVL refers to leader behaviors aimed at encouraging people to concentrate on prospective issues related to digital technologies and to prepare for unforeseen setbacks in the future. Leaders who are technologically vigilant and prioritize the anticipation of potential issues in SSCSCM will significantly reduce followers' complacency and foster a sense of duty to implement constructive changes for success in this domain. Executives with an optimistic perspective on the implementation of environmental practices are more inclined to enhance their companies' engagement in environmental management [73]. The use of environmental management accounting provides enhanced visibility of environmental information to numerous stakeholders [39], and this visibility significantly positively influences environmental practices [40]. Environmental management accounting was developed to assist companies in identifying, measuring, and managing the costs related to natural resource utilization, waste production, and pollutant emissions, thereby enhancing organizational transparency regarding environmental expenses, improving resource efficiency, minimizing waste, and reducing operational costs [51]. Environmental accounting refers to a method of accounting that prioritizes and integrates environmental, social, and economic information of business organizations in the processes of accounting and reporting [74]. From a social standpoint, environmental management accounting can enhance corporate reputation and foster trust among stakeholders by evidencing a concrete commitment to sustainability, potentially resulting in heightened consumer loyalty and improved relations with local communities [75]. These arguments aid in the formulation and development of the following hypothesis.

- *Hypothesis 4 (H4). DEMA is likely to mediate the relationship between TVL and SSCSCM*

The research model, based on the produced hypotheses and variables, is illustrated in Figure 1:

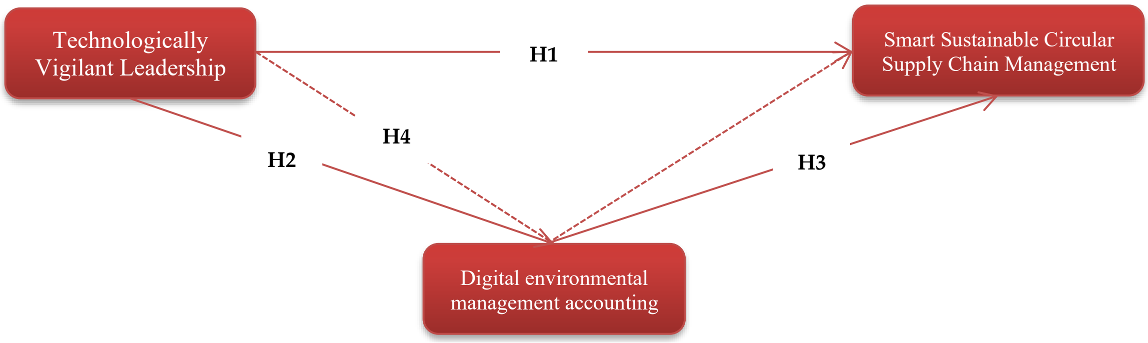

Figure 1. Conceptual model and hypotheses

4- Research Methodology

4-1- Research Philosophy and Paradigm

This study employed a positivist strategy to assure triangulation and theoretical validity. Based on the perspectives of Park [76], positivism corresponded with the hypothetico-deductive model of scientific inquiry, which necessitated the testing of hypotheses based on established assumptions and empirical data through the creation of standardized variables, terminology, and metrics. Consequently, positivist research methodology relied on a solitary quantitative approach termed the mono-method, making regression a prevalent quantitative analytical instrument in positivist studies due to its compatibility with this specific method. Despite facing increasing criticism from diverse competing perspectives, positivism, in its multiple forms, continued to be the prevailing epistemological approach utilized in the field of management sciences [77]. Positivist researchers predominantly employed survey methodologies, including structured interviews and closed questionnaires. Consequently, proponents of positivism prioritized the extraction of quantitative data in numerical form, perceiving it as more "objective" and scientific compared to researchers' "subjective" interpretations of occurrences.

4-2- Research Approach and Design

To ensure consistency, the study employed a quantitative approach through a questionnaire survey, deemed suitable for testing existing formulations, evaluating theories, and conducting objective assessments among constructs and variables in alignment with the positivist paradigm [78]. The study utilized a cross-sectional approach, collecting data at a singular point in time to assess the relationships among the variables. This methodology enabled a comprehensive analysis of the interactions between TVL, DEMA, and SSCSCM.

4-3- Measurement Scale

The physical format of the questionnaire was utilized to get data from the respondents. In accordance with previous studies, the scale variables and questionnaires were formulated to correspond with the research context of Vietnamese SMEs. A prototype version of the survey questionnaire was developed after a thorough review of relevant literature and established validated scales. This study employed the collaborative and iterative process established by Douglas and Craig [79] to translate the original English version of the scales into Vietnamese. Initially, the modified items were independently translated by two researchers and two language professors from two universities. The inconsistencies in the input have been resolved and concluded. The translated version was subsequently pre-tested with ten executives from the SMEs. After setting up the questionnaire, a pilot test verified the concept interconnections and ensured participant clarity. A 35-person pilot test was conducted. Hair et al. [80] used Cronbach's α value to assess questionnaire construct internal consistency, requiring 0.7 or above for acceptable reliability. Internal consistency reliability studies found that the questionnaire's Cronbach's alpha value exceeded 0.7, confirming its reliability and consistency [80]. The current research used the seven-point Likert scale from 1 = "strongly disagree" to 7 = "strongly agree" for all measurement scales. The summary of constructs with corresponding scale items was demonstrated in Table 1.

Table 1. Summary of model-related constructs and scale items

Construct	Scale items	References
	Technologically vigilant leadership	
Task-oriented behavior		Gerpott et al. (2019) [81]; Abbu et al. (2023) [82]; Gao et al. (2024) [27]
	TO1: Our managers identify and articulate issues or solutions regarding the adoption of digital technologies, delineating the relationships between these problems or answers within the context of digital technology adoption.	
	TO2: Our managers disseminate information, referencing others who may possess the necessary expertise and assigning responsibilities within the discourse.	
	TO3: Our managers evaluate the costs and benefits of adopting digital technologies.	
Change-oriented behavior		
	COH1: Our managers delineate the goals or visions.	
	COH2: Our managers prioritize tasks and procedures in accordance with the objective or vision.	
	COH3: Our managers express a commitment to transformation and novel concepts, assume accountability for executing change and innovation, and engage in action planning.	
Relational-oriented behavior		
	RO1: Our managers engage attentively and endorse the proposals of others.	
	RO2: Our managers commend digital initiatives adopted in our enterprise through affirmative statements.	
	RO3: Our managers promote the involvement of internal and external stakeholders in the enterprises' digital transformation activities.	
	Digital environmental management accounting	
Environmental cost		Abdelhalim et al. (2023) [57], Fuzi et al. (2022) [83]
	EC1: Our enterprise utilizes digital tools to evaluate environmental expenses.	
	EC2: Our enterprise utilizes digital technologies to allocate environmental expenses to production processes and products/services.	
	EC3: Our enterprise creates and employs accounts designated for environmental expenditures.	
Environmental regulation		
	ER1: Our enterprise is dedicated to environmental regulation.	
	ER2: Our enterprise adheres to the environmental policies.	
	ER2: Our enterprise uses digital technologies to tackle environmental concerns.	
Environmental safety		
	ES1: Our enterprise enhances safety awareness.	
	ES2: Our enterprise adheres to environmental safety regulations.	
	ES3: Our enterprise supplies safety requirements.	
Management commitment		
	MC1: Employees are dedicated to use digital technologies environmental initiatives.	
	MC2: Management commitment fosters and endorses environmental management.	
	MC3: Management commitment entails making decisions regarding environmental issues.	
Customer and stakeholder focus		
	CSF1: Our enterprise is dedicated to ensuring customer and stakeholder satisfaction through using digital technologies.	
	CSF2: Our enterprise is dedicated to fulfilling the requirements of customers and stakeholders while delivering value to them through using digital technologies.	
	CSF3: Our enterprise promotes sustainable practices to its consumers and stakeholders through using digital technologies.	
	Smart sustainable circular supply chain management	
Circular economy supply chain management design		Wan et al. (2023) [84]; Kayikci et al. (2022) [85]
	CESCD1: Our enterprise utilizes digital technologies to enhance supply chain efficiency and diminish logistics demand.	
	CESCD2: Efficient and circular transportation methods are employed between supply chain locations.	
	CESCD3: Our enterprise utilizes digital technologies to devise and enhance methods for recycling waste materials and spare components.	
Circular economy supply chain relationship management		
	CESCRM1: Our enterprise utilizes digital technologies to improve the provision of circular economy-friendly items, which have been evaluated from suppliers.	
	CESCRM2: Our enterprise utilizes digital technologies to assist current suppliers in formulating rules and regulations pertaining to circular economy principles.	
	CESCRM3: Our enterprise utilizes digital technologies to collaborate with suppliers in order to mitigate the environmental, social, and economic impacts of product manufacture and consumption.	
Circular economy human resource management		Kim et al. (2019) [86]; Kayikci et al. (2022) [85]
	CEHRM1: Our enterprise offers sufficient training to improve employees' professional skills and digital technology utilization to advance circular economy management as a fundamental organizational principle.	
	CEHRM2: Our enterprise evaluates the employee's proficiency in utilizing digital technologies in relation to their alignment with circular economy principles during performance assessments.	
	CEHRM3: Our employees comprehensively grasp the scope of the enterprise's circular economy policy.	

4-4- Sampling and Data Collection

The main data in this study were obtained through two sample units. The primary sample unit consisted of organizations, while organizational accountants served as the secondary sampling unit. The present study focused on SMEs situated in Vietnam. The accountants were responsible for executing the control mechanisms and strategizing the organization. Due to the investigation's temporal and financial limitations, the sample for this study was generated by convenience sampling and snowball sampling methods. Convenience sampling was the predominant form of non-probability sampling, emphasizing the acquisition of data from participants who were readily accessible to the researcher. In the meanwhile, snowball sampling was a non-probability sampling method in which extant subjects actively seek out additional subjects to include in the sample. This approach allowed for the interaction with individuals who were previously inaccessible, thereby facilitating access to those who were previously unknown. The target audience was initially accessed through convenience sampling. Researchers could access a significantly larger pool of potential participants who satisfied the criteria of this study through these participants. The researchers requested permission from the senior management of the companies to acquire the contact details of the accountants before inviting them to participate in the study.

Before disseminating the surveys to the individuals in person, the researchers obtained their informed consent. This would reduce the likelihood of participants responding incorrectly to surveys, and researchers would be able to assure them that their personal information were confidential and anonymous. The participants may withdraw at any time and for any reason. The research predominantly concentrated on the accounting department employees of SMEs in Vietnam. In order to ascertain eligibility, the subsequent criteria were implemented: (i) The participants must be currently employed in a SME; (ii) They must have a minimum of five years of work experience; and (iii) They must be willing to participate in the research. Participants who were recruited for the study but did not meet the eligibility criteria were excluded. Gupta [87] proposed that the ideal sample size should range from 5:1 to 20:1, with 5 and 20 being the sample size for each individual item, respectively. Data was gathered from the beginning of August 2024 to the end of December 2024. Following the evaluation of the questionnaires, the final sample comprised 356 valid replies, resulting in a data loss rate of 28.80 percent. The sample's socio-demographic profile indicated that males constituted 57.58 percent of participants, whereas females represented 42.42 percent. The study indicated that persons aged "41-50" comprised 54.21 percent of the overall sample. The age group "31-40" constituted around 37.36 percent. In contrast, the groups classified as "20-30" and "above 51" represented a minimum of 4.78 and 3.65 percent, securing the lowest ranks among the previously described categories. The majority of participants possessed at least a Bachelor's Degree in academic qualifications. The respondents have almost eight years of collective expertise in accounting.

4-5- Data Analysis Technique

This work employed two statistical software tools, WarpPLS 7.0 and SmartPLS 4.1.0.9, for data analysis. Linear relationships were analyzed using CB-SEM in SmartPLS 4.1.0.9, whereas non-linear relationships were examined with WarpPLS 7.0. The recent emergence of software tools for non-linear route studies, such as WarpPLS, enabled researchers to account for non-linearity in determining coefficients of relationship among interconnected variables [88]. WarpPLS utilized a curve-fitting methodology to assess both linear and nonlinear relationships by endeavoring to fit an S-shaped or U-shaped curve to the dataset. WarpPLS's identification of an S- or U-shaped curve could yield a more accurate estimation of the associations among latent variables [89].

5- Research Result Analysis

5-1- Common Method Bias

Several steps were conducted to mitigate the impact of common method bias. To begin, we offered a number of solutions to reduce the possibility of bias in the data collection process. We implemented strategies to minimize ambiguity and made sure that the constructions used were unaffected by outside forces while we were gathering data. The TVL, DEMA, and SSCSCM components were also validated by expert evaluations. In order to ascertain the potential presence of common method bias in the study results, this study implemented Harman's single-factor test. The statistical result underscored that the first factor represented just 16.377% of the variance, which was less than the widely accepted threshold of 50% [90]. Therefore, the investigation was not influenced by any evidence of a common method bias threat.

5-2- Model Fit Indices

Model fitness evaluations were performed utilizing standard assessments with the support of SmartPLS 4.1.0.9, including Chi-square/df; p-value; Root Mean Square Error of Approximation (RMSEA); Goodness of Fit Index (GFI); Adjusted Goodness-of-Fit Index (AGFI); Comparative Fit Index (CFI); Parsimonious Goodness of Fit Index (PGFI); Standardized Root mean square residual (SRMR); Normed Fit Index (NFI); Tucker–Lewis Index (TLI). Accordingly, a significant value higher than 0.05 (p-value >0.050) emphasized that there was no difference between the sample covariance and the covariance of the prediction model. The statistical outcomes of model fit were illustrated in Table 2.

Table 2. Results of Model fit

Criteria	Acceptable fit	Value
Chi-square/df	≤ 3	1.085
P-value	>0.05	0.106
Root Mean Square Error of Approximation (RMSEA)	< 0.08	0.015
Goodness of Fit Index (GFI)	≥ 0.90	0.925
Adjusted Goodness-of-Fit Index (AGFI)	≥ 0.90	0.905
Comparative Fit Index (CFI)	≥ 0.90	0.992
Parsimonious Goodness of Fit Index (PGFI)	≤ 1.00	0.726
Tucker–Lewis Index (TLI)	≥ 0.90	0.990
Standardized Root Mean square residual (SRMR)	< 0.05	0.033
Normed Fit Index (NFI)	≥ 0.90	0.907

5-3- Measurement Model Assessment

In the context of establishing convergent validity, it was generally accepted that items possessed standardized factor loadings exceeding 0.6. The average variance extracted (AVE) for the constructs exceeded 0.5, thus providing further support for convergent validity. The value of composite reliability and Cronbach's alpha were higher than the cutoff value of 0.7. Consequently, the statistical outcomes in Table 3 proved reliability and convergent validity for further investigation.

Table 3. Results summary of reliability and convergent validity

Constructs and operationalization		Convergent validity		Construct reliability		Result
		Factor Loadings	AVE	Cronbach's Alpha	Composite Reliability	
Technologically vigilant leadership	**TVL**					
Task-oriented behaviour	TO	0.711 - 0.779	0.548	0.785	0.786	Retained
Relational-oriented behaviour	RO	0.786 - 0.834	0.644	0.844	0.844	Retained
Change-oriented behavior	COH	0.736 - 0.870	0.620	0.826	0.828	Retained
Digital environmental management accounting	**DEMA**					
Environmental cost	EC	0.763 - 0.817	0.626	0.834	0.835	Retained
Environmental regulation	ER	0.753 - 0.854	0.638	0.839	0.841	Retained
Environmental safety	ES	0.752 - 0.831	0.613	0.826	0.828	Retained
Management commitment	MC	0.705 - 0.790	0.551	0.784	0.786	Retained
Customer and stakeholder focus	CSF	0.709 - 0.783	0.576	0.801	0.802	Retained
Smart sustainable circular supply chain management	**SSCSCM**					
Circular economy supply chain management design	CESCD	0.710 - 0.807	0.582	0.806	0.803	Retained
Circular economy supply chain relationship management	CESCRM	0.726 - 0.812	0.614	0.825	0.827	Retained
Circular economy human resource management	CEHRM	0.740 - 0.843	0.634	0.837	0.839	Retained

The heterotrait-monotrait ratio (HTMT) was a statistical measure used to evaluate discriminant validity in the context of SEM. The HTMT ratio contrasted the average correlation among items that evaluated multiple constructs (heterotrait) to the average correlation among items that evaluated a single construct (monotrait). The statistical outcomes of the HTMT, which were notably lower than 0.85, were presented in Table 4.

Table 4. Results summary for discriminant validity on Heterotrait–Monotrait ratio

	CEHRM	CESCD	CESCRM	COH	CSF	EC	ER	ES	MC	RO	TO
CEHRM											
CESCD	0.390										
CESCRM	0.253	0.307									
COH	0.171	0.230	0.029								
CSF	0.173	0.239	0.179	0.136							
EC	0.169	0.352	0.189	0.234	0.361						
ER	0.194	0.133	0.196	0.066	0.285	0.292					
ES	0.120	0.147	0.148	0.131	0.176	0.301	0.188				
MC	0.212	0.373	0.186	0.171	0.384	0.231	0.167	0.196			
RO	0.113	0.181	0.173	0.069	0.095	0.140	0.089	0.098	0.185		
TO	0.337	0.399	0.334	0.371	0.223	0.334	0.260	0.174	0.295	0.345	

5-4- Structural Model Assessment

Direct effect. To evaluate the hypotheses, we established a structural model using CB-SEM in SmartPLS and PLS-SEM in Warp PLS (Refer to Table 5, Figures 2 and 3). Based on the outputs of CB-SEM carried out in SmartPLS 4.1.0.9, TVL had a positive and statistically significant effect on SSCSCM (β = 0.415; p-value < 0.01). In the same vein, the output of PLS-SEM carried out in WarpPLS 7, TVL had a positive and statistically significant effect on SSCSCM (β = 0.283; p-value < 0.001). Thus, H1 was empirically supported. The outputs of CB-SEM carried out in SmartPLS 4.1.0.9 corroborated the positive and significant relationship between TVL and DEMA (β = 0.557; p-value < 0.001). Likewise, the outputs of PLS-SEM carried out in WarpPLS 7, TVL was verified to significantly and positively impact DEMA (β = 0.351; p-value < 0.001). Thus, H2 was empirically supported.

Table 5. Hypotheses, and path coefficient for SmartPLS and Warp PLS, and the shape of relationships

Relevant path	SmartPLS		WarpPLS		
	Path coefficient	p-value	Path coefficient	p-value	Shape of relationship in Warp PLS
Direct effect					
TVL → SSCSCM	0.415	< 0.01	0.283	< 0.001	Non-linear S-shaped
TVL → DEMA	0.557	< 0.001	0.351	< 0.001	Non-linear S-shaped
DEMA → SSCSCM	0.465	< 0.01	0.290	< 0.001	Non-linear S-shaped
Indirect effect					
TVL → DEMA → SSCSCM	0.259	< 0.01	0.100	< 0.01	Partial mediation
R^2	$R^2_{DEMA} = 0.310$; $R^2_{SSCSCM} = 0.604$		$R^2_{DEMA} = 0.123$; $R^2_{SSCSCM} = 0.220$		

The outputs of CB-SEM carried out in SmartPLS 4.1.0.9 also revealed the significant and positive impact of DEMA on SSCSCM (β = 0.465; p-value < 0.01). Similarly, the outputs of PLS-SEM carried out in WarpPLS 7 substantiated that DEMA affected SSCSCM in a significant and positive manner (β = 0.290; p-value < 0.001). Thus, H3 was empirically supported. The values of R^2 for DEMA and SSCSCM were reported to be 0.310 and 0.604, respectively, based on the outputs of CB-SEM carried out in SmartPLS 4.1.0.9. The outputs of PLS-SEM carried out in WarpPLS 7 highlighted that the values of R^2 for DEMA and SSCSCM were 0.123 and 0.220, respectively.

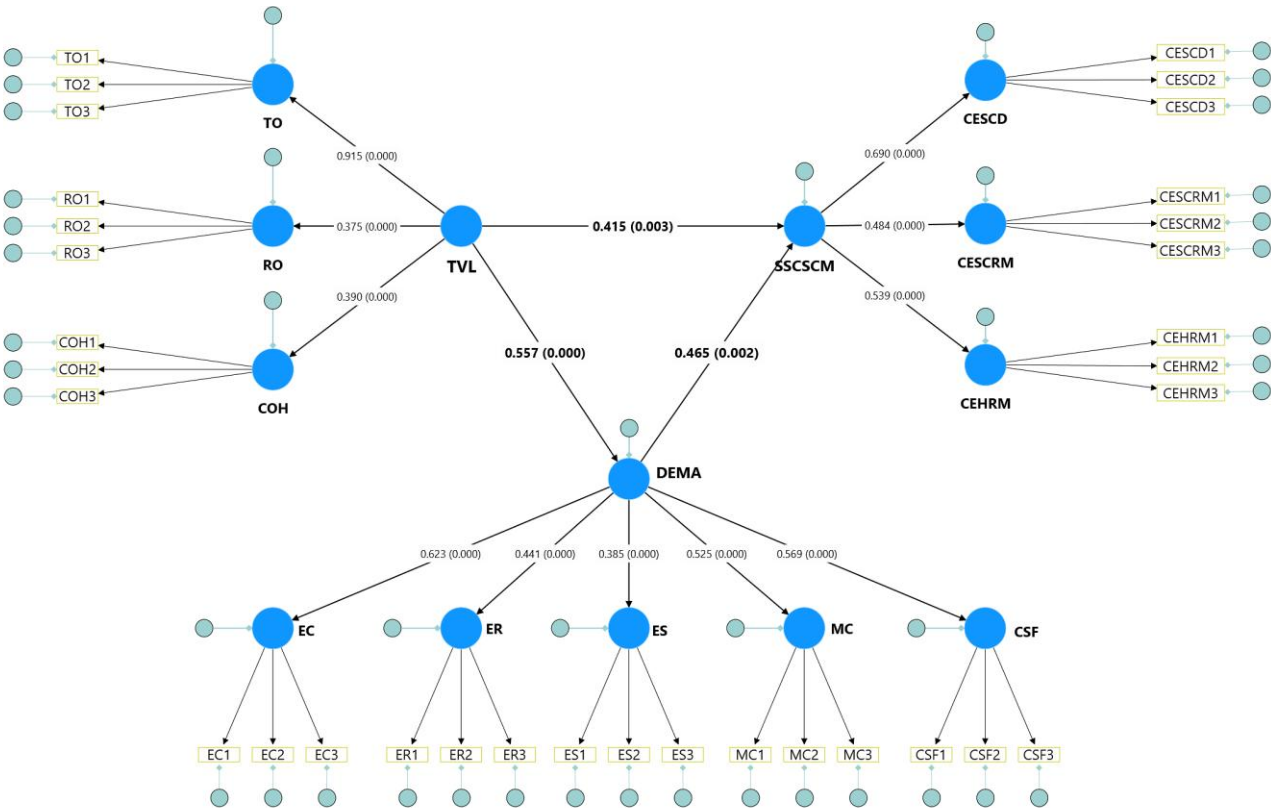

Figure 2. Structural model

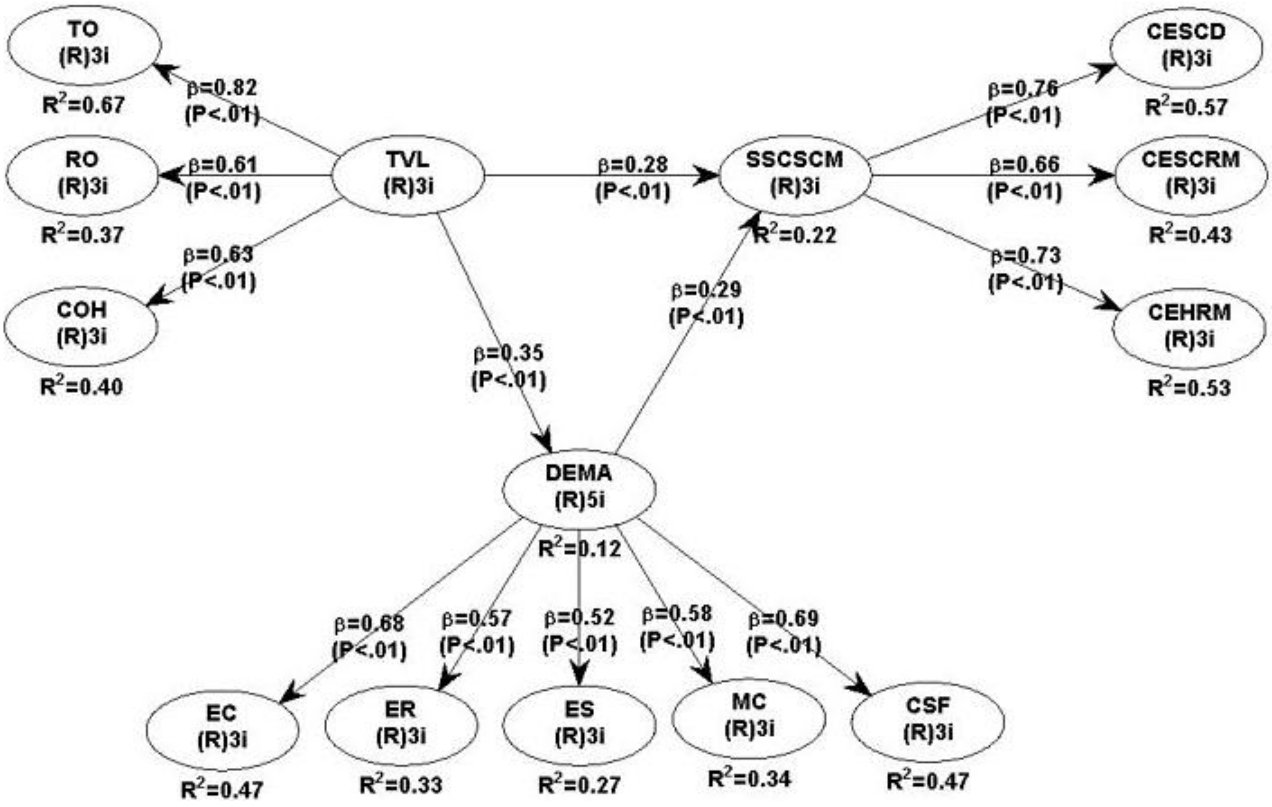

Figure 3. Structural model

Indirect effect. Based on the outputs of CB-SEM carried out in SmartPLS 4.1.0.9, the direct effect of TVL on SSCSCM was supported and the indirect effect was significant (β = 0.259; p-value < 0.01). Similarly, the outputs of PLS-SEM carried out in WarpPLS 7, the direct effect of TVL on SSCSCM was supported and the indirect effect was significant (β = 0.100; p-value < 0.01). In the nutshell, it confirmed that DEMA partially mediated the relationship between TVL and SSCSCM. Thus, H4 was empirically supported.

Structural model diagram in Figure 2 displayed path coefficient and p-value; this picture was derived from SmartPLS 4.1.0.9 and illustrated the path directions for H_1–H_3 based on empirical data collected in 2024.

Structural model diagram Figure 3 displayed R square and path coefficients; this picture was derived from WarpPLS 7.0 and illustrated the path directions for H_1–H_3 based on empirical data collected in 2024.

5-5- Discussion and Implication

Implication in theory. Based on the statistical outputs, TVL has a positive and statistically significant effect on SSCSCM. The correlation between TVL and SSCSCM was non-linear, displaying a S-shaped pattern. As TVL rose, its impact on SSCSCM likewise escalated, although there existed a threshold beyond which the effect stabilized. To the best of our knowledge, this could be among the few study that focuses on the impact of TVL on SSCSCM in SMEs in a developing country. Most prior research emphasizes the potential influence of transformative leadership in supply chain management (i.e., [63-65]). The pivotal element for attaining efficacy in quality management processes and business excellence frameworks is leadership capability [91], which significantly influences supply chain performance [92]. The findings of this research widen the growing body of literature on the competencies of supply chain manager (i.e., [59-62]). The shift to Industry 6.0 has catalyzed the redefinition of supply chain management towards smarter, more sustainable, and circular approaches. TVL refers to leader behaviors aimed at encouraging people to concentrate on prospective issues related to digital technologies and to prepare for unforeseen setbacks in the future. Leaders who are technologically vigilant and prioritize the anticipation of potential issues in SSCSCM will significantly reduce followers' complacency and foster a sense of duty to implement constructive changes for success in this domain.

A statistically significant non-linear (S-shaped) relationship existed between TVL and DEMA. This indicated that an ideal level of TVL may result in efficient DEMA. This suggested that there existed an optimal level of TVL that enhanced the performance of DEMA; however, the effect stabilizes thereafter. To the best of our knowledge, this could be among the few study that focuses on the impact of TVL on DEMA in SMEs in one developing country. Arief [93] asserts that businesses must acknowledge the impact of leadership and anticipate future transformations in the accounting field. The findings of this research are partially in line with the results of previous studies (i.e., [94, 95]). Based on the research of

Karimi and Walter [89], when digital leadership becomes stronger, the effects of digital transformation on cloud-based accounting effectiveness will be enhanced. According to Afifa et al. [95], the research of transformational leadership is revealed to moderate the interconnection between blockchain technology, digital accounting practices, and sustainable performance. Environmental management accounting has become essential in directing sustainable company activities [27]. Among the numerous environmental management systems available, the environmental management accounting system can be particularly advantageous for the organization in identifying, gathering, employing, and analyzing diverse forms of accounting information pertinent to its environmental management. Empirical findings provided by Schaltegger et al. [96] indicated that numerous managers value and analyze diverse types of environmental data.

The correlation between DEMA and SSCSCM was statistically significant and exhibited a non-linear (S-shaped) pattern. As the efficacy of DEMA escalated, its impact on SSCSCM likewise intensified, although there existed a threshold beyond which the effect stabilized. To the best of our knowledge, this could be among the few study that focuses on the impact of DEMA on SSCSCM in SMEs in a developing country. The domain of environmental management accounting has consistently garnered interest in recent years [36]. The obtained findings are partially consistent with the observation acquired in prior studies (i.e., [72, 97]). More concretely, Appannan et al. [72] advocated for organizations to implement targeted environmental strategies to enhance their environmental performance using environmental management accounting. Latifah **&** Soewarno [97] also asserted that the environmental accounting strategy influences waste management, hence improving sustainability performance in micro, small, and medium enterprises. The supply chain is becoming expensive, complex, uncertain, and susceptible, but managers persist in their pursuit of more economical, expedited, and superior supply networks. To address these difficulties, supply chains must become smarter and adopt circular practices [66]. Industry 6.0 technologies can serve as essential facilitators of a circular economy by aiding in the management of goods flow, enabling automatic position tracking and analysis of natural resources, and optimizing waste-to-resource alignment in industrial symbiosis networks through real-time data collection for improved resource management. Nonetheless, despite the inherent flexibility and versatility of a smart sustainable circular supply chain, SMEs must be adequately prepared to address supply chain difficulties and disruptions. In this context, DEMA might serve as helpful tools for addressing these concerns. DEMA can be pondered as the internal management instrument to enable enterprises to recognize potential ecological impacts by serving as a mechanism for implementing financial controls and strategies for environmental management.

Implication in practice. The significance of SSCSCM as a strategic environmental initiative that enhances sustainable development can be recognized by managers in SMEs in Vietnam and similar environments. In order to address the distinctive challenges and opportunities that SMEs and locally held enterprises face, managers should contemplate the development of adaptable and targeted strategies. This entails the adoption of new technologies, the promotion of innovation, and the willingness to take calculated risks in order to enhance the enterprise. Consequently, strategic decisions that are consistent with long-term objectives are made, including the investment in infrastructure that facilitates business growth. As a result, SMEs will be able to enhance the performance of their smart sustainable circular supply chain operations by increasing their investment in Industry 6.0. The results corroborate that TVL can provide substantial advantages to SSCSCM. Consequently, managers should concentrate on the strategic advantages of this leadership style. As a result, the development of TVL is a critical factor in guaranteeing the long-term success and sustainability of the circular supply chain of SMEs. Lastly, the results of this study suggest that the SME can effectively acquire useful information to develop SSCSCM, which can contribute to better sustainable performance, through the use of effective DEMA. Consequently, SME managers should prioritize the establishment, development, and enhancement of the organization's learning capability by investing in resources and assets, as well as increasing their awareness of the importance of DEMA. In order to facilitate the efficient and systematic learning of employees, managers should integrate, collaborate, and coordinate the knowledge and experiences acquired through the implementation of DEMA within the organization. They should also organize training sessions and apprenticeship programs that prioritize the acquisition of in-depth knowledge in the fields of environmental management accounting and digital technology.

6- Conclusion

With the rise of globalization complicating supply systems, researchers have broadened the focus of leadership beyond the individual to the supply chain level, investigating the suitable characteristics of supply chain leaders. The DEMA has consistently demonstrated its significance as a vital instrument for advancing sustainable business practices by enabling data-driven decisions that enhance business performance across all three dimensions [72]. The main aim of this study is to explore how TVL impacts SSCSCM in the context of Industry 6.0. This is accomplished by analyzing the mediating effect of DEMA on the relationship between TVL and SSCSCM. This research evaluated the proposed model using two distinct statistical methods within the framework of structural equation modeling, which facilitated the assessment of both linear and non-linear correlations among the constructs. The data was obtained from a sample of respondents employed in SMEs. Linear relationships were analyzed using SmartPLS, whereas non-linear relationships were examined with WarpPLS. In both instances, the influence of TVL on SSCSCM was significant and positive, as demonstrated by CB-SEM in SmartPLS 4.1.0.9 and PLS-SEM in WarpPLS 7.0. Furthermore, DEMA partially mediated the relationship between TVL and SSCSCM. More concretely, as TVL rose, its impact on SSCSCM and DEMA likewise escalated, although there existed the thresholds beyond which the effects stabilized. In the same vein, the obtained findings indicated that an ideal level of DEMA may result in efficient SSCSCM. This suggested that there existed an optimal level of DEMA that enhanced the performance of SSCSCM, however the effect stabilizes thereafter. Keeping these findings in mind, SMEs will be capable of formulating strategic operating strategies and allocating resources effectively. Refrain from excessively dedicating resources to a certain task, since this would render it redundant and hinder SMEs from enhancing their operational performance.

This study encountered numerous limitations that may directly or indirectly affect the outcomes. This study was undertaken in Vietnam, a developing country. In order to facilitate the generalization of its conclusions to other comparable nations, the researchers are recommended undertaking more future investigations to analyze the study model and its implementation by gathering original data from various countries. Secondly, this study employed a cross-sectional approach for the collection of primary data. It is advisable for researchers to collect primary data longitudinally in future studies to enhance the reliability of the findings. Thirdly, a single respondent from each organization was targeted, hence augmenting the likelihood of common bias method manifesting although several statistical methods were utilized to reduce common bias methods. Nevertheless, this study cannot entirely rule out the potential for common bias method. To mitigate the incidence of this damage, it is essential to engage many respondents from each industrial organization to complete the study questionnaire. This study employed stakeholder theory, and future research may incorporate more theories to bolster the model and its findings.

7- Declarations

7-1- Author Contributions

Conceptualization, P.Q.H. and V.K.P.; methodology, P.Q.H. and V.K.P; software, P.Q.H.; validation, P.Q.H.; formal analysis, V.K.P.; investigation, P.Q.H. and V.K.P; resources and data curation, P.Q.H.; writing—original draft preparation, P.Q.H.; writing—review and editing, P.Q.H.; visualization, P.Q.H.; supervision, P.Q.H.; project administration, P.Q.H.; funding acquisition, P.Q.H. All authors have read and agreed to the published version of the manuscript.

7-2- Data Availability Statement

The data presented in this study are available on request from the corresponding author.

7-3- Funding

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7-4- Acknowledgement

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7-5- Institutional Review Board Statement

Not applicable.

7-6- Informed Consent Statement

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

7-7- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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