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RESEARCH PAPER

Sustainable supply chain maturity in Hi-Tech agriculture startups: an ANP analysis for industry 5.0 evolution in an emerging market

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Abstract

This paper examines the maturity level of sustainable supply chains within hi-tech agri-startups in emerging markets with Vietnam as a case study. We also use the Analytic Network Process (ANP) method to pinpoint and identify the key factors influencing the maturity level of sustainable supply chains in Vietnam's burgeoning sector. The findings reveal that the maturity level of Vietnamese agri-startups within the supply chain is notably lacking, particularly in storage, distribution, and collaboration, achieving less than 70 percent of other startups. In stark contrast, these startups demonstrated exceptional performance in production development and commercialization, followed closely by management. These results underscore the significant advantages that participation in sustainable supply chains offer to agri-startups. Key influencing factors driving this success include product innovation, strategic planning, agility, and a willingness to take risks - all bolstered by essential technical support. However, it is noteworthy that financial resources, digital marketplaces, blockchain technologies, and mobile applications seem to exert a relatively limited influence on their growth. The paper distinguishes itself by targeting the unique context of hi-tech agri-startups in emerging economies. Furthermore, by leveraging institutional theory, this study vividly illustrates how grassroots innovation and policy alignment can effectively mitigate institutional voids. It situates its findings within a comparative framework, yielding insights that are not only relevant to Vietnam but also applicable to other emerging economies.

Keywords

Agri-startups, maturity model, sustainable supply chain, ANP model

Introduction

Sustainable supply chain management (SSCM) has become significantly important in recent decades due to ongoing global issues and changing expectations from consumers and governments. Recent disruptions in raw material availability and transportation have compelled businesses to adopt more sustainable methods to ensure long-term resilience and success. SSCM necessitates cooperation throughout the supply chain, which involves companies collaborating with their partners to address sustainability across different supply chain functions.

Emerging economies, especially those with large agrarian populations engaged in subsistence farming, offer

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unique prospects for sustainable innovation. Subsistence farmers face limited financial resources, small farming plots, and dependence on traditional agricultural methods. Governments have promoted agri-startups – key players in transforming agriculture through innovative, efficient, and sustainable practices to alleviate these issues and uplift rural communities. By integrating technology with traditional farming, these startups enhance productivity, reduce waste, and optimise resource use. Additionally, they contribute to rural development by generating employment, encouraging entrepreneurship, and boosting economic activity, thus fostering a more sustainable and prosperous agricultural sector. Agri-startups are essential in enhancing sustainability and efficiency in agriculture by optimising existing resources, improving resilience to climate change, and adopting innovative practices like robotics and precision farming inputs. Within the transition toward Industry 5.0, hi-tech agri-startups are uniquely positioned to operationalise its core pillars in terms of empowering farmers and rural workers through digital decision-support tools and inclusive innovation processes (i.e., the pillar of human-centric technology adoption); advancing circular resource management, climate-adaptive production models (i.e., the pillar of sustainable resource optimisation); and flexible, digitally enabled supply chain coordination capable of responding to environmental and market disruptions (i.e., the pillar of resilience-oriented supply chain design) (Rahim et al. 2025; Singh et al. 2025; Hammad et al. 2026). Such focuses align with the growing research interest in emerging markets, which have become critical participants in global supply chains due to globalisation and international business activities. Previous studies, such as those by Sánchez-Flores et al. (2020), underline the need for more research on SSCM trends in emerging markets. Similarly, Geng et al. (2017) stress the requirement for empirical data concerning sustainable supply chains within manufacturing contexts across Asian emerging economies.

Vietnam exemplifies these dynamics as a notable emerging economy that values agriculture and hosts a burgeoning entrepreneurial landscape in high-tech agriculture. Agri-startups in Vietnam are starting to significantly influence the enhancement of sustainability, efficiency, and innovation in agricultural practices. However, the entrepreneurial segment in high-tech agriculture is still in its infancy, with many startups relying on low-tech solutions. These startups face unique challenges, such as high initial costs linked to sustainable practices, vulnerability to climate change impacts, and market fluctuations, while striving to incorporate environmental stewardship, resource efficiency, and ethical standards. Although maturity models have been widely applied in SSCM research in developed nations (Ho et al. 2020; Fu et al. 2020), similar studies in emerging economies like Vietnam are sparse. Rajeev et al. (2017) identified data availability as a major barrier to SSCM research in emerging markets, further underscoring the necessity for focused studies within these areas. The agri-startups in Vietnam present a compelling case for evaluating sustainable supply chain maturity as they navigate the opportunities and challenges of this evolving sector. For instance, it provides an analytically relevant case as it combines rapid economic transition, strong integration into global agri-food supply chains, and a high proportion of smallholder-based agriculture – features commonly observed across many emerging markets. While not intended to represent all emerging economies, Vietnam offers a contextually grounded example that enables theory-informed insights into SSCM maturity under resource-constrained and institutionally evolving conditions. It is noted that Sánchez-Flores et al. (2020), for example, have called for increased empirical research to bridge the gaps in SSCM pathways and trends in emerging economies.

This study utilises the ANP model to examine the sustainable supply chain maturity levels of Vietnamese agri-startups. The model systematically identifies the factors impacting supply chain maturity and explores how these startups engage with and adapt to sustainable supply chain practices. While earlier research has looked at the determinants of SSCM, it has often focused on developed nations. This research provides new insights by offering empirical evidence regarding the maturity levels of sustainable supply chains specific to Vietnamese agri-startups.

The findings from this study present practical recommendations for enhancing the maturity and performance of sustainable supply chains. These strategies aim to empower agri-startups to evaluate their current state, implement improvement strategies, and achieve greater resilience and sustainability. By focusing on Vietnam, this study fills a significant gap in the SSCM literature and provides actionable insights relevant to emerging markets globally.

Literature

Sustainable supply chain in emerging economies

Sustainable supply chains have become increasingly vital, especially in emerging markets where they are crucial in addressing global challenges, operational risks, and growing environmental demands. These supply chains are integral to balancing efficiency and sustainability, coordinating the flow of products, materials, finances, and knowledge across interconnected networks of suppliers, distributors, and end-customers (Zhou et al. 2018; Manfredi and Capik 2022). Factors such as hi-tech applications, collaboration, market access, and resource sharing influence supply chain maturity in emerging economies.

Agriculture often forms the backbone of economic and social structures in emerging markets, yet it is predominantly characterised by subsistence farming. Small-scale farmers typically face limited capital, outdated technology, and restricted market access. To tackle these issues and improve rural livelihoods, governments and private sectors are increasingly fostering the growth of agricultural startups. These agri-startups act as catalysts for innova-

tion, bridging the gap between technology and agriculture through advancements like robotics, precision farming, and efficient resource utilisation. By bolstering productivity, reducing waste, and optimising resource allocation, agri-startups contribute to rural development, generating employment, encouraging entrepreneurship, and stimulating economic growth, positioning themselves as pivotal agents for sustainable transformation.

Sustainable supply chains in emerging markets emphasise environmental stewardship, resource efficiency, and ethical practices, which lead to reduced waste, lower carbon footprints, and improved product quality. However, challenges persist, such as high initial costs of sustainable practices, climate-related risks, and market volatility. Addressing these barriers requires meticulous planning, targeted government support, and collaborative innovation among stakeholders. Integrating local sourcing, farm-to-table logistics, and digitised frameworks further enhances supply chain resilience and sustainability, essential for navigating environmental and operational risks.

Emerging economies like China, India, Iran, Brazil, and Vietnam have implemented sustainable procurement, production, distribution, and reverse logistics practices, reflecting their commitment to sustainability (Govindan et al. 2014; Geng et al. 2017). While these initiatives strengthen infrastructure and resilience, these markets face unique challenges, including informal supplier networks, unethical business practices, and gaps between regulatory implementation and enforcement. Social and cultural dimensions, such as poverty and social justice, add complexity to sustainable supply chain operations (Carter et al. 2015). Environmental concerns, including greenhouse gas emissions and the increasing electricity demand, underscore the importance of integrating sustainability with technological advancements (Hingne and Agarwal 2021).

Maturity models provide valuable frameworks for evaluating sustainable supply chain processes, identifying developmental gaps, and charting growth trajectories. Comprehensive models emphasise collaboration and coordination, essential for long-term sustainability (Hansali et al. 2022). Recent studies, such as those by Sánchez-Flores et al. (2020), highlight the need for empirical evidence in emerging markets better to understand sustainable practices and their impact on firm performance. With their growing global importance and market potential, emerging economies are key players in driving innovative, sustainable, and resilient supply chain solutions.

Vietnam exemplifies the challenges and opportunities faced by emerging markets. The entrepreneurial movement in high-tech agriculture within Vietnam is still nascent, with many agri-startups relying on low-tech applications. Despite this, they are essential for transforming agricultural practices and advancing sustainability. This study utilises the maturity model and ANP to evaluate supply chain maturity levels among Vietnamese agri-startups, providing insights into factors influencing supply chain maturity and the benefits of active participation in sustainable networks. Recommendations include optimising resource utilisation, building resilience to climate risks, and fostering stakeholder collaboration. These strategies enable agri-startups to assess and elevate their current practices while offering scalable solutions for sustainable supply chain development across emerging markets.

In summary, sustainable supply chains are fundamental to the growth and resilience of emerging economies, particularly in agricultural sectors. Research consensus calls for expanded investigations into sustainable supply chains within these contexts to address unique challenges and leverage their potential for global economic and environmental progress.

The maturity of the sustainable supply chains

The maturity model concept has been a significant focus in management research for many years. First introduced in the 1970s within the information systems field, it was designed to monitor the performance of the information systems function. Nolan and Gibson (1974) are recognised as the initial developers of this idea. They created a four-stage maturity model (initiation, expansion, formalisation, and maturity) to assess the maturity of an information system's functions across different areas. Each stage of the maturity model tackles various practices to advance process maturity from one level to the next. The term "maturity" in organisations signifies a state of development, reflecting the transition from an initial to a more sophisticated stage (Lahti et al. 2009). A mature organisation is characterised by well-defined processes, supported with documentation and training, uniformly implemented across projects, and consistently monitored and refined by its users (Lahti et al. 2009). Although there are many maturity models, they all typically outline multiple dimensions or process areas at various maturity levels and describe the usual performance associated with each level. The lowest tier indicates the most underdeveloped state, while the highest tier represents full development, though the number of levels can differ depending on the specific model (Correia et al. 2023). It is noted that traditional supply chain maturity models are generally industry-agnostic, primarily focusing on process integration, coordination mechanisms, and organisational capabilities across diverse sectors (Lahti et al. 2009; Correia et al. 2017). In contrast, more recent studies have begun to propose maturity frameworks specifically tailored to high-tech or smart agriculture, emphasising digital integration, data governance, and technology-enabled farm management capabilities. These agriculture-specific maturity approaches highlight sector-unique challenges such as interoperability of smart farming technologies, real-time data utilisation, and digitally supported decision-making within agricultural production systems (Senna et al. 2023; Hohagen and Wilkens 2025; Fares et al. 2025).

Three notable frameworks illustrate the development of maturity in emerging markets: Poirier's four-level model from 1999, the five-stage model proposed by Correia and col-

leagues in 2023, and the Capability Maturity Model Integration (CMMI) (Ho et al. 2016). All in all, the level of maturity in sustainable supply chains indicates how well a supply chain incorporates sustainability practices across environmental, social, and economic aspects. Researchers have created maturity models to evaluate this, often employing a five-level framework (from a Very-low to a Very-high stage, see Table 1) that assists organisations in identifying their current sustainability engagement and areas that require enhancement.

These models generally assess:

- Sustainability practices within and between organisations (how companies collaborate on sustainability efforts).
- The Triple Bottom Line (TBL) approach (balancing environmental, social, and economic considerations).
- Key areas for sustainability, including eco-design, ethical sourcing, and reducing waste.

Organisations can utilise these models for self-assessments, to create improvement roadmaps, and as benchmarking tools to compare their sustainability advancements with industry benchmarks. The TBL framework – economic, environmental, and social factors – is vital in evaluating SSCM practices. Elkington (1997) underscores the significance of this framework in his publication, "Cannibals with Forks: The Triple Bottom Line of 21st Century Business." Other prominent research, such as that conducted by Seuring and Müller (2008), Pagell and Wu (2009), and Corallo et al. (2024) further investigates the concept of sustainable supply chains.

Environmental dimension: This area concentrates on diminishing environmental impacts through eco-design, ethical sourcing, and waste minimisation strategies. Sustainable supply chain practices seek to lower ecological footprints and enhance resource efficiency.

Social dimension: The social dimension emphasises fair labor practices, community involvement, and equitable trade. It underscores the necessity of tackling social issues, particularly in developing markets where challenges like labor rights and community development are paramount.

Economic dimension: The economic facet guarantees that sustainability initiatives are financially sustainable and support long-term profitability. It involves balancing cost efficiency and environmental and social responsibilities, ensuring sustainable initiatives foster economic growth.

Sustainability assessment research indicates that 50% of the studies analysed encompass all three components of TBL. However, many still concentrate on only one or two dimensions, often neglecting social performance. This gap is particularly pronounced in developing markets, where concerns regarding fair labor practices and community involvement are crucial (Mani et al. 2016; Yawar and Seuring 2017). Moreover, the economic aspect is frequently assessed only alongside environmental factors, overlooking the intricate interrelationships among the TBL components (Esfahbodi et al. 2017). The TBL framework offers a thorough approach to evaluating and enhancing the sustainability of supply chains. Organisations can comprehensively understand their sustainability efforts and pinpoint improvement areas by addressing environmental, social, and economic elements.

Table 1. The maturity level of a sustainable supply chain in emerging economies.

Level	Characteristic	Previously used by
Very-low	- The supply chain and its practices are unstructured and ill-defined. - Process measures are not in place. Process performance is unpredictable. - Targets, if defined, are often missed. - Customer satisfaction is low. - Functional cooperation is also low. - Practices may originate from the initial experience or knowledge of a team member.	Ghazinoori et al. (2020); Ho et al. 2020
Low	- Regulatory compliance processes are defined and documented. - Process performance is more predictable. - Targets are defined but still missed often. - Overcoming the functional silos takes considerable effort owing to boundary concerns and competing goals. - Customer satisfaction has improved but is still low.	Ghazinoori et al. (2020); Ho et al. 2020
Moderate	- Sustainability is considered in the supply chain, for suppliers, and in reporting metrics. - Cooperation between intra-company functions, vendors and customers takes the form of teams that share common supply chain management measures and goals that reach horizontally across the supply chain. - Process performance becomes more predictable, and targets are often achieved. - Customers are included in process improvement efforts, and customer satisfaction begins to show marked improvement. - Organic product standards are accepted for relevant processes and are used to improve the process to meet organic requirements. - Standard collaboration processes are proactively managed and spread consistently across the organisation.	Hynds et al. 2014; Gouvinhas et al. 2019; Ghazinoori et al. (2020)

Level	Characteristic	Previously used by
High	- Sustainability is integrated throughout much of the enterprise, including production, marketing, public metrics, and reporting, and it is used as a competitive advantage in some markets. - Detailed measures of supply chain performance are collected and statistically analysed. - Special causes of collaboration process variation are identified and corrected to prevent future occurrences. - Collaboration occurs strategically, with integrated and coordinated strategies to achieve overall supply chain performance among multiple parties. - Organic standards are fully implemented for the relevant processes.	Edgeman and Eskildsen 2014; Ho et al. 2020
Very-high	- Sustainability is fully integrated throughout the enterprise, viewed not as an initiative but as the company's fundamental way of doing business. - Interaction occurs across all chain organisations, and collaboration aims to achieve maximum supply chain effectiveness. - Collaboration between legal entities is routine, with advanced sustainable supply chains that allow the transfer of responsibility without legal ownership. - At this level, trust, mutual dependency, and esprit de corps are the glue holding the extended supply chain together. - Process performance and reliability of the extended system are measured, and joint investments in improving the system, along with the returns, are shared.	Ho et al. 2020; Ghazinoori et al. (2020); Correia et al. 2023

Source: Authors' collection.

Agri-startup and factors impacting the maturity of sustainable supply chain

Agricultural startups, commonly known as agri-startups, are essential in tackling global agricultural issues by embracing innovative technologies and methodologies. These newly established, operational, and independent businesses aim to enhance agricultural productivity, sustainability, and profitability. Agri-startups concentrate on various domains, such as precision agriculture, biotechnology and genomics, robotics, and automation, all to address food security, climate change, and sustainable farming practices. Precision agriculture employs cutting-edge technologies such as GPS, IoT, and sensors to enhance crop management, leading to significant yield improvements and cost reductions. Biotechnology and genomics focus on creating high-yield, disease-resistant crops using genetic engineering and gene editing techniques. Robotics and automation facilitate tasks like planting and harvesting, increasing overall efficiency (Kim et al. 2020). Contemporary agri-startup business models utilise technologies such as blockchain to enhance transparency, sustainability, and economic efficiency within the supply chain. These models minimise food waste, guarantee traceability, and incorporate small-scale farmers into modern supply chains, improving their access to technology, markets, and financial resources. The direct-to-consumer model enables farmers to eliminate intermediaries, achieving better prices while offering consumers fresh, often organic products (Zhang et al. 2002).

Ongoing research, creative business approaches, and supportive regulations are crucial for agricultural startups' advancement and significant influence. Startups facilitate connections among farmers, consumers, suppliers, and service providers, improving market access and enhancing supply chain efficiency. Startups champion sustainable practices, including organic farming and water conservation, resulting in long-lasting environmental and financial advantages. Agri-startups also employ smart farming techniques, AI-based analytics, and IoT monitoring to boost efficiency and sustainability. Collaborating with technology companies, financial institutions, and logistics providers optimises the agriculutural supply chain. Efficient resource sharing among various partners lowers expenses and enriches market access (Chi et al. 2020). In developing countries, sustainable production focuses on appropriate material sourcing, waste minimisation, and collaboration with suppliers to create environmentally friendly products. Strategic partnerships and coalitions are vital for sustainable development, emphasising recycling initiatives and waste management to reduce adverse environmental effects. Successful supply chain management hinges on managing operations, ensuring quality project execution, overseeing risks, and providing training. Supplier engagement involves forming strategic relationships with suppliers for product development, production foresight, and inventory oversight to guarantee timely deliveries and shared information. Sustainable supply chains aim to reuse, remanufacture, and recycle products, thereby lessening environmental impacts from raw material procurement to disposal. The effectiveness of connections in sustainable supply chains encompasses clear communication, punctual delivery, and precise invoicing. Startups encounter uncertainties, including climate shifts, market fluctuations, technological advancements, and regulations, necessitating strategies like diversification and insurance (Akhtar et al. 2016; Ho et al. 2023).

Collaboration and partnerships improve supply chain efficiency and competitiveness. Alliances among startups, farmers, distributors, and retailers enhance product development, resource allocation, and market access. Relationships between industry and academia, public-private

partnerships, corporate collaborations, and farmer cooperatives are pivotal in fostering sustainable supply chains (Sharma et al. 2021). The levels of collaboration maturity range from minimal engagement to highly integrated initiatives centered on sustainability targets. In emerging economies, partnerships are essential due to limited green resources and expertise. Cross-organisational collaboration boosts economic and environmental performance and fosters sustainable supply chain efforts. Manufacturing companies work closely with suppliers who have green competencies to create eco-friendly products. The regulatory environment and cultural influences shape the operations and innovation of agri-tech startups: favorable regulations, financial support, and protections for intellectual property foster development. Companies in developing countries are increasingly adopting sustainable practices to meet environmental regulations and societal demands. The accessibility of markets plays a crucial role in the success of sustainable supply chains. Key elements include effective inventory management, essential certifications, and financial resources. Innovations in technology, such as digital platforms and mobile apps, improve market access and enhance supply chain effectiveness. Agristartups focus on sustainable logistics, optimising transportation routes and employing advanced technologies to boost operational efficiency. Streamlined logistics help reduce expenses, mitigate losses, and maintain product quality, particularly through cold chain logistics for perishable items (Zhu et al. 2008).

Consumer demand plays a significant role in SSCM, particularly for smaller suppliers. Qian and Olsen (2019) examined how agricultural startups can leverage IoT, blockchain technology, and data analytics to bolster commercialisation and streamline supply chains. Effective customer management is essential for agri-startups (Mastos and Gotzamani 2022). Manufacturing organisations in emerging markets increasingly implement green initiatives due to environmental regulations and public scrutiny (Govindan et al. 2014). They adopt SSCM strategies, such as green purchasing and eco-friendly design, to remain competitive globally (Tseng and Chiu 2013). Resource dependence theory (RDT) provides insight into interorganizational collaborations necessary for acquiring green resources (Paulraj et al. 2006). Sustainable production entails using environmentally friendly inputs while generating minimal waste. Eco-design is integral to this process, aiming to lessen a product's environmental footprint throughout its life cycle (Zhu et al. 2007).

Previous research has identified factors that impact supply chain maturity, but there is a scarcity of studies focusing on sustainable supply chains for agri-startups in developing economies. Further empirical research is warranted in this field, particularly in the context of hi-tech agriculture in Vietnam. Integrating sustainability into SSCM in developing markets presents distinct challenges. Sánchez-Flores et al. (2020) advocate for global frameworks that consider economic, environmental, and social aspects. Rana et al. (2025) propose that digital transformation could address institutional gaps within supply chains, while Nguyen and Thanh (2021) highlight the importance of governance frameworks in promoting sustainable practices. Although digital technologies such as AI and IoT can revolutionise supply chains, their adoption in emerging markets remains limited. Greater integration of these technologies may enhance resource efficiency and stakeholder collaboration (Sánchez-Flores et al. 2020).

Methodology

Procedure and sample

This research employs a mixed-method approach incorporating both quantitative and qualitative information to address the literature gaps regarding SSCM in developing economies. It focuses on the agri-startup ecosystem in Vietnam, adhering to the suggestions made by Sánchez-Flores et al. (2020) for empirical case studies that explore sustainability practices in developing markets. Vietnam's Master Program on Hi-tech Agricultural Development (2021–2030) seeks to encourage the integration of advanced technologies in businesses, including agri-startups, to generate high-value agricultural items and improve supply chain sustainability. Our analysis is based on data collected through a survey of Vietnamese agri-startups participating in this initiative.

Quantitative component

The study employs a structured survey targeted at agri-startups participating in Vietnam's National Hi-Tech Agricultural Development Program. Following the methodology of Sánchez-Flores et al., the survey assesses the integration of sustainability dimensions-economic, environmental, and social-through specific indicators of supply chain maturity. Important metrics include digital adoption rates, stakeholder collaboration levels, and operational efficiency under resource constraints.

The research by Yildirim et al. (2022) discusses institutional voids, which lack formal market institutions that support business operations in emerging markets. These voids create business challenges, such as difficulties accessing resources, market information, and legal protection. The study analyses how companies navigate these voids and develop effective strategies in such environments. Villar et al. (2020) examine the impacts of foreign direct investment (FDI) on local economies and businesses, focusing on how FDI influences economic growth, technology transfer, and employment generation in host countries. It also considers the potential benefits and drawbacks of FDI, including the role of multinational corporations in shaping local market dynamics and the implications for sustainable development. Combined, these studies offer insights into the challenges and opportunities businesses face in emerging markets, particularly regarding institutional gaps and the effects of foreign investment. Statistical analysis methods will be used to validate the findings and identify patterns.

We selected agri-startups from seven key regions in Vietnam (Ha Nam, Hoa Binh, Sơn La, Phu Yen, Binh Dinh, Lam Dong, Dong Thap) due to their status as focal points for agri-startups in the country. A random sample of registered startups was chosen from a comprehensive list provided by local authorities in each area, identifying 476 startups, including 300 agri-startups and 176 other startups. We focused on those agri-startups and managed to interview their managers in collaboration with local authorities, achieving a 100% response rate. It is noted that these managers/experts were selected based on a minimum of 5–10 years of experience in agri-startups, sustainable agricultural supply chains, innovation management, or related academic research including founders, policy or ecosystem experts, and academic researchers to ensure both strategic and operational perspectives. Participants represented multiple stages of the agricultural value chain, enhancing the reliability of ANP pairwise comparisons through diverse sectoral expertise (see Table 2 for more details).

Table 2. Descriptive statistics of the sample.

Variables	Definition	Mean	Std. Dev
Age	Manager's age (in year)	33.21	5.92
Education	Manager's schooling year (in year)	14.32	0.66
Gender	1 = Male		0.50
	2 = Female		
Agri-startup types	1 = Crop farming	2.04	0.86
	2 = Livestock production		
	3 = Aquaculture production		
	4 = Agricultural services		
Region	1 = The Mekong Delta region	1.90	0.80
	2 = The South-Central region		
	3 = The Northwest region		
Startup years	The time since the business was established (in year)	10.05	0.56
Revenue	Monthly revenue (in million VND)	2.19	0.66
	1 = less than 100		
	2 = from 100 to 500		
	3 = from 500 to 1,000		
	4 = more than 1,000		
Job level	1 = Senior management level	1.05	1.46
	2 = Executive level		

Source: Author's estimation.

During this study, the model undergoes a thorough validation process before its application. The content validity assessment is rooted in pertinent literature. It entails consultation with a panel of experienced practitioners and academic experts who are well-versed in the subject matter and its contextual relevance. The researchers utilise a semi-interview method and a questionnaire tool to gauge the managers' level of agreement with the model. The resulting data is subjected to quantitative analysis through content validity ratio (CVR) to determine the suitability of the model's content. Additionally, a semi-structured interview with a questionnaire incorporating the Maturity model is administered to elicit the experts' concurrence on the model.

Qualitative component

We complement the quantitative analysis with semi-structured interviews of policymakers, supply chain stakeholders, and agri-entrepreneurs. Using insights from Sánchez-Flores et al., our questions address challenges and opportunities in Vietnam's market. Thematic analysis identifies barriers, enablers, and factors for scalability in SSCM.

Our approach includes both close-ended and open-ended inquiries. Close-ended questions use a five-point Likert scale to gauge agreement with the model, while open-ended questions seek respondents' opinions on the model. This study also synthesis secondary data from the literature review and reports from the Vietnamese Ministry of Investment and the General Statistics Office of Vietnam (GSO). The study was intended to provide a comprehensive understanding of the startup landscape.

Research methods and measures

Research methods

In Vietnam, startups significantly contribute to the economy. To enhance startup performance, Vietnam launched the Master Program on Hi-tech agricultural development under the National Hi-tech Development Program (2021–2030). The program aims to apply high-tech to produce high-value agricultural products and enhance the sustainability of supply chains. Studies like Ho et al. 2020; Correia et al. (2023); and Ghazinoori et al. (2020) use the Maturity

model to assess supply chain maturity levels. Our study also uses this model to evaluate 300 agri-startups across seven provinces: Ha Nam, Hoa Binh, Son La, Phu Yen, Binh Dinh, Lam Dong, and Dong Thap.

The maturity model is designed to help startups evaluate the maturity of their operations if they progress through several maturity levels before reaching advanced stages. The maturity level (MD) of each dimension is derived from the weighted average of all maturity items (MDIi) within the respective dimensions, with the weighting factor (gDIi) representing the average importance rating from all 300 managers for each item. The maturity level is computed using the following formula:

$$M_D = \frac{\sum_{i=1}^{n} M_{DIi} * g_{DIi}}{\sum_{i=1}^{n} g_{DIi}}$$

In which:

M_D: Maturity

D_{Ii}: Dimension

g_{DIi}: Weighting factor

n: number of maturity items

Besides, the paper also employs the ANP model developed by Saaty (2004) to analyse the impact of various factors on the maturity level of sustainable supply chains, comparing agri-startups' efficiency to give their choice for joining the supply chain. Accordingly, the ANP supermatrix was developed by defining clusters and interdependencies from literature and expert input, then aggregating pairwise comparisons using the geometric mean to produce the unweighted, weighted, and limit supermatrices. Judgments with a consistency ratio (CR) above the acceptable threshold of 0.10 were returned to experts for revision through iterative feedback rounds, while outliers showing deviations greater than 20–25% from the group geometric mean were reviewed collectively to ensure consensus (Ngo et al. 2021). Convergence of the limit supermatrix was confirmed when weight changes were below 0.001 between iterations, and sensitivity analysis was conducted by increasing and decreasing key weights by 10 percent to verify the robustness of the final priority results. Consequently, the equation for evaluating the effectiveness of participation in the supply chain is based on this analysis:

$$F = S_1X_1 + S_2X_2 + S_3X_3 + ...+ S_nX_n$$

In which:

S_k (k = 1 ÷ n): weighted values of the criteria taken from Table 3

x_k (k = 1 ÷ n): expert evaluation results for each criterion of each option.

Measures

The focal point of our analysis is the concept of entrepreneurship, gauged through survey inquiries. Table 3 presents comprehensive explanations and operationalisation of all variables employed in this investigation. The maturity level indicators in this study evaluate the extent to which employees actively propose ideas and surpass the requirements outlined in their job descriptions, aligning with our defined parameters.

Table 3. Operationalisation of variable.

Indicators	Definition	Criteria	Code
Sustainable supply chain (SSC)	Sustainable supply chain management integrates environmental, social, and economic factors into its practices to achieve long-term sustainability.	Environmental sustainability	SSC1
		Socioeconomic sustainability.	SSC2
		Economic sustainability	SSC3
Hi-tech (HT)	The integration of advanced technologies to enhance productivity, sustainability, and supply chain efficiency in agriculture.	Information systems and statistical Techniques for demand forecasting	HT1
		Availability of modern ICT	HT2
		Use of mobile devices	HT3
		Utilization of machine-to-machine communication	HT4
Storage and distribution (SD)	Storage and distribution in agri-startups involve the preservation, handling, and transportation of agricultural products to maintain quality and reduce post-harvest losses	Inventory management	SD1
		Warehousing	SD2
		Supply chain management	SD3
		Logistics and cold chain management	SD4
		Transportation optimization	SD5
		Last-mile delivery	SD6
Source sharing (SS)	Source sharing in agri-startups refers to the collaborative use of resources like machinery, land, knowledge, and technology to reduce costs and increase efficiency	Technical support	SS1
		Farming equipment support	SS2
		Marketing equipment support	SS3
Processes (PS)	Systematic operations that enhance productivity, sustainability, and profitability.	Precision farming method	PS1
		Irrigation method	PS2
		Cultivation method	PS3
		Quality control method	PS4

Indicators	Definition	Criteria	Code
Market Access (MA)	The ability to connect farmers with consumers through direct sales, e-commerce, cooperatives, and export channels.	Maintaining adequate inventory levels	MA1
		Certification for quality assurance	MA2
		Market information	MA3
		Financial resources	MA4
		Mobile applications	MA5
		Fintech innovations	MA6
		Customer satisfaction management	MA7
Collaboration (CO)	Collaboration involves communication and joint efforts	Linking for creating and planning products	CO1
		Linking for getting information, profits, and resources	CO2
		Research institutions and other stakeholders	CO3
Environment (EN)	Sustainable practices that minimize ecological impact while maximizing productivity.	Legal issues concerning organic farming, climate-smart agriculture	EN1
		Credit incentives promoting the use of renewable energy in farming operations	EN2
Management (MN)	Planning, organizing, and optimizing resources to ensure efficiency and growth.	The quality of supply chain project management	MN1
		Risk management	MN2
		Supply chain management training and awareness	MN3
		Climate and weather risks management	MN4
Product development and commercialization (PC)	A structure for developing and bringing new products to the market in collaboration with customers and suppliers. Commercialization involves a carefully planned three-tiered product rollout and marketing strategy	Ideation phase management	PC1
		Business process management	PC2
		Stakeholder stage management	PC3

Source: Collection by authors.

Each of these items was measured using a five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree). The practical importance of each maturity item was rated on a Likert-scale ranging from "not important" (rating = 1) to "very important" (rating = 5). For example, the item "Existence of Hi-technology - HT" was rated with an average importance of 3.5 out of 4, whereas "utilisation of mobile devices" was rated with 3.2. The overall average of the 12 elements for 64 items is 3.2 out of 4, which valid our model's content. An illustration of our ANP analysis is further provided in Fig. 1.

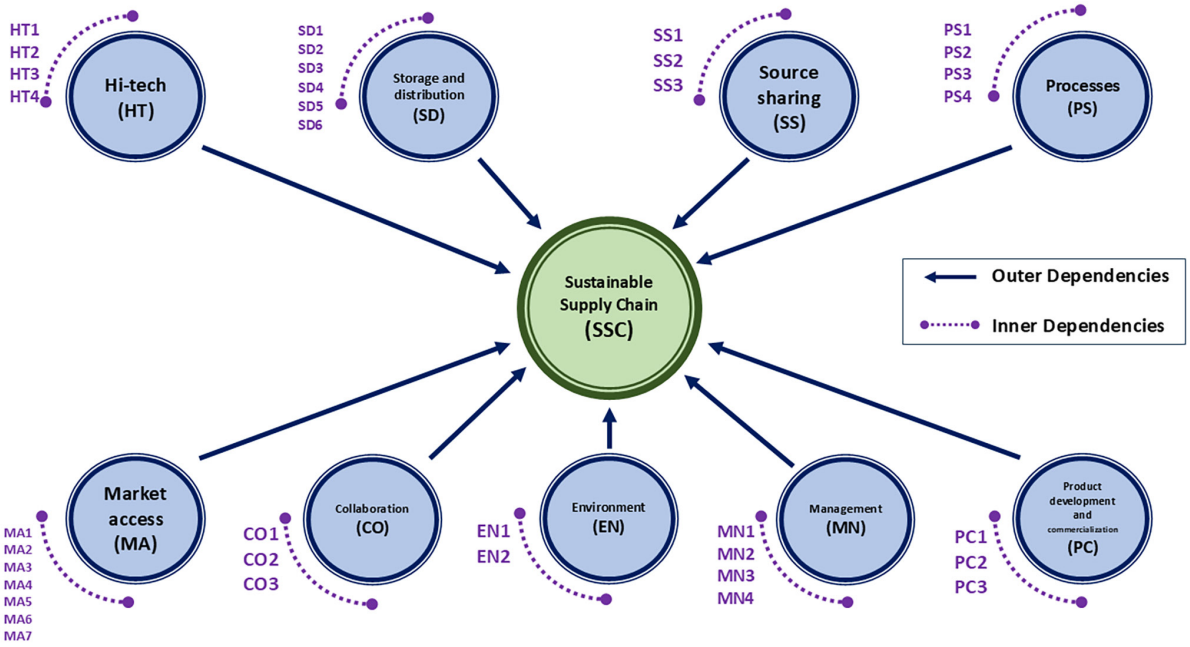

Figure 1. ANP flowchart. Source: Author's creation.

Results and discussion

Results of the assessment of the maturity level for the sustainable supply chain of agri-startups

According to the Survey with 300 agi-startups, the results show the level of maturity in sustainable supply chain. The results in Fig. 2 show that the level of maturity, including sustainability in the economy, environment, and society, are 2.59, 3.24, and 2.96, respectively. Agri-startups apply basic supply chain management processes, which are defined and documented. Process performance is more predictable. Targets are defined but still missed more often than not. Customers are included in process improvement efforts, and customer satisfaction begins to show marked improvement, but is still low. Agri-startups start to take care of environmental sustainability. Organic product standards are accepted for relevant processes and are used to improve the process to meet organic requirements. The Maturity model results show that other startups have a sustainable supply chain maturity level of above 3, higher than agri-startups, especially market access, with a maturity level of 4.02.

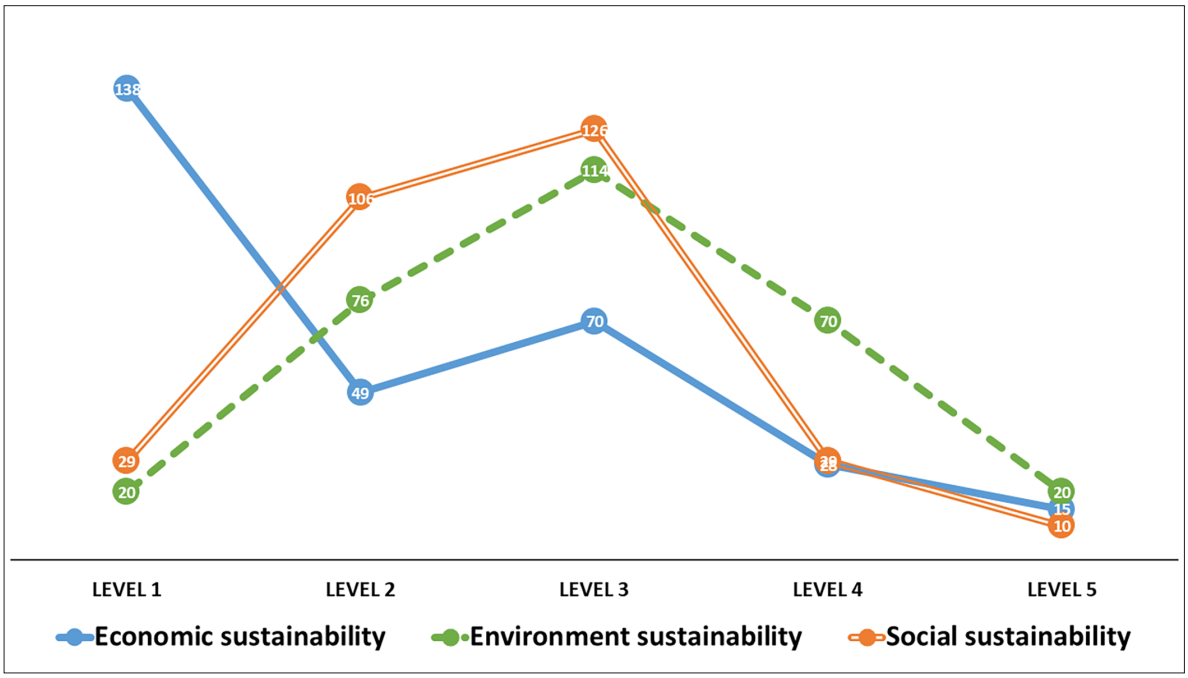

Figure 2. The level of maturity of the sustainable supply chain of agri-startups. Source: Author's estimation.

In Fig. 3, the maturity level in the 12 dimensions is visualized. A radar chart depicts the overall result. The survey results show that the level of maturity for the sustainable supply chain in agri-startups is lower than that of all agri-startups, with around level 2 for all factors.

The various facets and significance of the subject highlight the necessity of giving specific attention to the supply chain of agri-startups and offering solutions and tools for its enhancement. The outcomes of implementing this model in the two supply chains of agri-startups and other startups reveal that agri-startups achieved the highest scores in product development and commercialisation (2.93), and management (2.70). Product development and commercialisation are pivotal stages for any agri-startup striving to introduce innovation to the agricultural sector. The process commences with identifying the needs and challenges within the agricultural domain, such as enhancing crop yield, minimising environmental impact, or optimising supply chain efficiency. Startups frequently allocate resources for innovation and research and development (R&D) endeavors, which may encompass experimenting with new agricultural technologies, breeding novel crop varieties, or devising sustainable farming methodologies. Subsequently, upon validating the product, startups frequently concentrate on expanding production, which may involve forming partnerships with farmers, investing in manufacturing infrastructure, or securing supply chains for essential inputs. Notably, agri-startups in Vietnam also know new requirements for storage and distribution are elicited and realised by cultivating new utility values. They understand new concepts of contexts of use and their improvements for storage and distribution are envisioned by being restudied and analysed from the present users' viewpoints. Establishing a robust brand and marketing strategy is indispensable for customer attraction, which may entail emphasising the product's sustainability, efficiency, and innovation. Integrating production across the value chain has yielded advantages for cooperatives and farmers, reducing intermediary stages, decreasing production costs, and amplifying product value (Ho et al. 2020).

The findings indicate that supply chain maturity scored lowest in storage and distribution (2.09) and collaboration

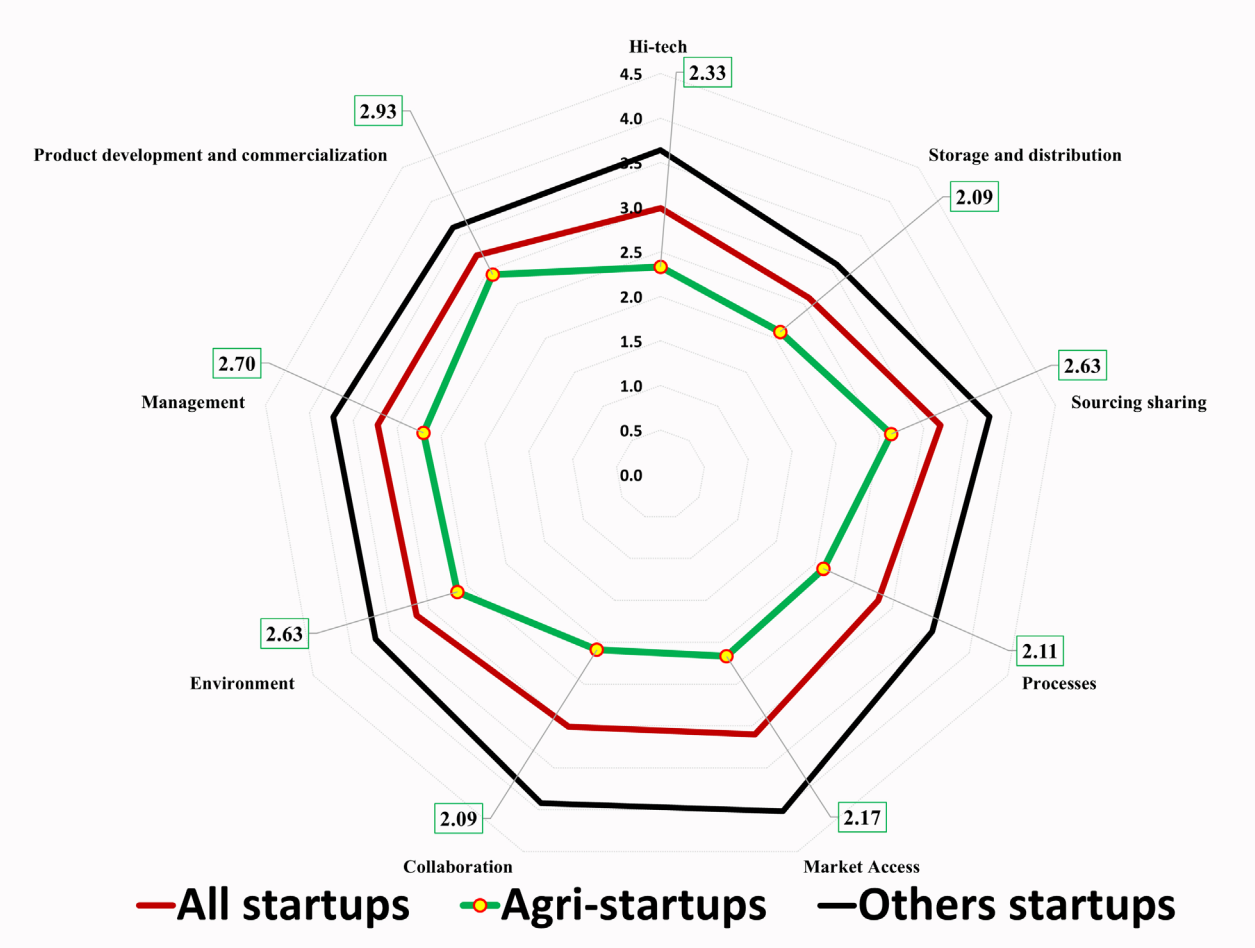

Figure 3. The level of maturity of factors affecting the sustainable supply chain of agri-startups. Source: Author's estimation.

(2.09). Conversely, other startup supply chains achieved the highest scores in market access (4.02), collaboration (3.92), and customer relations (3.83), while scoring lowest in storage and distribution (3.08) and processes (3.52). The agri-startups have developed informal electronic channels to support exchanging and sharing technical-scientific information (Facebook, networks, blogs). Existing competing products are assessed. Users are involved in the design process. However, they do not have metrics to understand how to conduct comparative analysis of competing products at appropriate points in the product life cycle. Customers still do not have full access to the information they need. Collaboration also plays a critical role in scaling operations, ensuring product quality, and delivering value to end-users within the agricultural supply chain of startups. Coordinating efforts across such a diverse group can be challenging, mainly due to varying goals, priorities, and technological adoption levels within agri-startups. Moreover, agricultural production often occurs in rural or remote areas, leading to logistical challenges in coordinating activities and maintaining consistent communication across the supply chain (Ghazinoori et al. (2020)). With level 2, collaboration with suppliers, distributors, technology providers, research institutions, and other stakeholders about creating and planning products, sharing information, profits, and resources is not very close collaboration. Only few agri-startups put the supply chain goals before its local goals. As such, this imbalance could lead to the situation that while product development shows higher maturity (as startups prioritise innovation, prototyping, and market responsiveness to survive early competition), operational integration across logistics actors remains limited and fragmented. Therefore, it is reasonable that storage/distribution and collaboration are weaknesses of Vietnamese agri-startups; the businesses need to improve those aspects to participate in the Industry 5.0.

In the supply chain of agri-startups, the customer factor is rated at 2.53, indicating a lower level of maturity. This is primarily attributed to the limited direct or online communication channels that hinder widespread customer interaction. Consequently, improvements in this aspect are imperative, such as developing a comprehensive event checklist, establishing essential infrastructure, and formalising response procedures in collaboration with industry practitioners (Hansali et al. 2022). In these agri-startups, the informal processes for identifying cus-

tomer service events, evaluation, and implementation of the solution, cooperation between teams and departments in the field of information transfer, dealing with events, formulating performance evaluation forms, and establishing basic performance evaluation measures are low. However, with level at 2.53, agri-startups also begin to build the coordination between process and strategic goals, procedures, process related criteria and perception by team members, use of techniques, tools and take care of solutions to improve decisions, coordination and integration between different departments and internal stakeholders for the data exchange, collecting and analysing detailed performance information according to customers.

The challenges associated with storage and distribution (SD) with 2.09 are particularly pronounced in the context of agri-startups. With this level, the agri-startups in Vietnam develop only informal electronic channels to support exchanging and sharing technical-scientific information (Facebook, networks, blogs). However, agri-startups in Vietnam lack a comparative analysis of competing products at appropriate points in the product life cycle. Besides, these agri-startups develop projects to reduce negative environmental impacts. However, they have not integrated aspects of sustainability through an environmental management department or specific functions for this issue. These results necessitate implementing swift and efficient storage and distribution processes to forestall spoilage and ensure the delivery of fresh products to consumers. However, managing cold, temperature-controlled supply chains can be intricate and costly, particularly in regions with limited infrastructure. Especially in numerous rural areas, storage facilities may be outdated or insufficient, increasing the likelihood of losses from spoilage, pest infestations, or suboptimal storage conditions. So agri-startups must address transportation challenges, including poor road conditions, a shortage of reliable transportation options, and substantial distances separating farms and markets (Wieland 2016).

ANP results on factors affecting the maturity level of the sustainable supply chain of the agri-startups

The Exploratory Factor Analysis (EFA) method was used to uncover the underlying structure of a relatively large set of variables. The EFA analysis of 16 observation variables across four elements, which have a tangible impact on leader behaviours, yielded a Kaiser-Meyer-Olkin (KMO) measure of 0.872 (greater than 0.5) and a significant Bartlett test with p-value <0.000. Five factors were extracted at an Eigenvalue of 1.221 (greater than 1), and the Approximate Chi-Square measure was 54.23% (greater than 0.5). Furthermore, 45 observation variables with 12 elements were statistically significant. A standard analytical method with the ANP technique was employed to assess the actual status of the factors affecting the sustainable supply chain of agri-startups. The results revealed that each group of factors has different levels of impact on the sustainable supply chain of agri-startups.

Following a statistical analysis using SPSS software, the author discovered 19 criteria with an average value of "Mean" greater than 3.5. These 19 criteria were selected to join the sustainable supply chain assessment efficiently. The evaluation results for the criteria of the two types of agri-startups are displayed in Table 4.

Table 4. Factors Influencing the Maturity of Sustainable Supply Chains in Agri-Startups.

Criteria	Not joining the SSC		Joining the SSC	
	Weight	Expert assessment (%)	Weight	Expert assessment (%)
HT				
HT1	0,40	76.65	0,40	76.78
HT2	0,21	39.50	0,21	39.62
HT3	0,20	40.54	0,20	39.34
HT4	0,20	39.60	0,20	39.51
SD				
SD1	0,36	74.63	0,37	76.54
SD2	0,14	38.64	0,14	37.37
SD3	0,14	38.98	0,14	37.37
SD4	0,17	36.61	0,18	37.37
SD5	0,18	37.98	0,18	37.37
SS				
SS1	0,54	80.49	0,54	98.17
SS2	0,20	56.91	0,20	54.26
SS3	0,25	52.71	0,26	54.26
PS				
PS1	0,43	86.90	0,44	88.66
PS2	0,21	43.28	0,21	43.98
PS3	0,15	51.77	0,13	43.98
PS4	0,21	41.80	0,22	43.98
MA				
MA1	0,18	61.99	0,20	66.38

Criteria	Not joining the SSC		Joining the SSC	
	Weight	Expert assessment (%)	Weight	Expert assessment (%)
MA2	0,10	19.67	0,10	19.69
MA3	0,09	22.63	0,08	19.34
MA4	0,10	19.80	0,12	19.19
MA5	0,10	19.86	0,13	19.22
MA6	0,10	19.80	0,11	19.42
MA7	0,54	94.26	0,54	96.06
CO				
CO1	0,56	94.84	0,59	99.91
CO2	0,21	61.90	0,20	55.95
CO3	0,23	63.61	0,21	43.25
EN				
EN1	0,47	90.62	0,47	95.87
EN2	0,54	91.26	0,54	94.06
MN				
MN1	0,45	90.36	0,46	97.93
MN2	0,18	44.80	0,17	45.94
MN3	0,20	44.80	0,21	45.94
MN4	0,17	44.80	0,17	45.94
PC				
PC1	0,27	68.50	0,27	73.65
PC2	0,28	82.35	0,28	94.10
PC3	0,21	49.47	0,21	57.20

Source: Author's estimation.

In the realm of agricultural startups, the level of supply chain maturity is significantly shaped by factors highlighted through the ANP. The top influencing factors include CO1 (99.91%) and SS1 (98.17%), while factors like MA3 (19.34%), MA4 (19.19%), and MA5 (19.22%) suggest areas that could benefit from improvement. A well-developed supply chain enhances cost efficiency in transportation, storage, and production, allowing startups to lower product prices and boost their competitiveness in the market. Agricultural startups in emerging markets can refine their supply chain processes by adopting the principles of Industry 5.0, such as human-machine collaboration and state-of-the-art technology integration. Incorporating resilience into supply chains is vital for managing risks that arose post-COVID-19, like supplier disruptions and geopolitical issues. Establishing thorough quality audits, supplier assessments, and regulatory compliance measures is crucial to maintaining production standards. As Vietnam advances into Industry 5.0, embracing cutting-edge technologies like AI, IoT, and blockchain is essential for creating smart, interconnected supply chains. For instance, IoT-driven machine-to-machine communication (HT4) transforms logistics and precision agriculture, enhancing risk management and operational efficiency.

However, agricultural startups in Vietnam and comparable emerging markets encounter obstacles in fully utilising digital marketplaces, blockchain, and mobile applications due to limited financial resources and the unique characteristics of agricultural products. Governments and policymakers must prioritise financial incentives, infrastructure improvements, and training programs to address these challenges. By enhancing access to modern digital platforms, startups will be better positioned to attract investments and accelerate their integration into sustainable supply chains. Engaging in sustainable supply chains is particularly beneficial for agricultural startups. Survey data indicate that those involved in these systems achieve an operational effectiveness score of 29.75, compared to 27.90 for those not participating. These startups can access markets directly by eliminating traditional intermediaries, leading to higher profits and stable revenue. Their emphasis on producing high-quality, sustainable products also meets consumer demands and fosters improved farming practices, aligning with global sustainability objectives.

The study highlights significant relationships between advanced technologies and supply chain components. For instance, the strong positive correlation (0.773) between HT1 (high-tech tools) and SS3 (sustainable supply chain practices) underscores technology's transformative capacity to enhance supply chain maturity. Conversely, weak correlations in other areas, such as HT4 and SS1 (0.086), present opportunities for focused interventions to reinforce these connections.

Vietnam's recovery following COVID-19 presents a unique chance to align supply chain strategies with the principles of Industry 5.0. Cold chain logistics (SD4) are now crucial for maintaining the quality of agricultural exports, while digital payment systems (MA6) are revolutionising financial transactions for farmers. E-commerce platforms (MA5) allow startups to engage directly with consumers, enhancing market access and sustainability. Collaborative partnerships, including those facilitated by research institutions and backed by government incentives (CO3 and EN2), foster agricultural innovation.

In summary, the post-pandemic landscape presents an exciting opportunity for agricultural startups to harness the

groundbreaking advancements of Industry 5.0. By optimizing their supply chain operations through innovative strategies, these startups can not only enhance efficiency but also champion sustainability initiatives that resonate with today's eco-conscious consumers. This forward-thinking approach cultivates resilience and sets the stage for these companies to emerge as trailblazers in the quest for a sustainable future.

Conclusion and recommendations

This research makes a significant contribution to the ongoing academic discourse surrounding sustainable supply chains within developing markets, with a particular emphasis on high-tech agricultural startups in Vietnam. By systematically evaluating the maturity levels of sustainable supply chains and investigating the impact of various critical factors, this study seeks to address notable gaps in the existing literature concerning supply chain dynamics in emerging economies. By leveraging institutional theory, this study vividly illustrates how grassroots innovation and policy alignment can effectively mitigate institutional voids, echoing the discussions presented by Yildirim et al. (2022). Moreover, it situates its findings within a comparative framework, yielding insights that are not only relevant to Vietnam but also applicable to other emerging economies. This research enriches the current body of literature and offers actionable solutions for policymakers and practitioners dedicated to strengthening supply chain resilience and sustainability. By bridging the gap between Industry 5.0 and sustainable supply chains - while also tackling the challenges introduced by the post-COVID-19 landscape – this study paves the way for future explorations into sustainable agricultural systems in developing markets.

Utilizing a robust dataset drawn from 300 agricultural startups, this analysis employs the Maturity Model and ANP models to gain comprehensive insights. The findings reveal a striking disparity in maturity levels, particularly highlighting that agricultural startups have the lowest maturity scores in two crucial areas: storage/distribution and collaboration. In contrast, startups from other sectors reported significantly higher scores in vital areas such as market access and customer satisfaction. These results underscore an urgent necessity for targeted strategies aimed at enhancing the operational and collaborative capabilities of agricultural startups. Furthermore, expert insights emphasize that proactive engagement in sustainable supply chains significantly boosts the operational effectiveness and market competitiveness of these startups. This points to an imperative need to tackle persistent challenges faced by agri-startups, including inadequate digital tools and limited access to technical expertise and financial resources. By addressing these challenges, stakeholders can foster an environment conducive to the growth and sustainability of agricultural startups in Vietnam and similar emerging markets.

Regarding the practical implications, this study proposed three crucial recommendations to offer a clear roadmap for (agri)startup managers and policymakers as follows:

Firstly, it is crucial to improve the storage and distribution systems for Vietnamese agri-startups. By implementing groundbreaking innovations such as cold chain technology, which ensures the preservation of perishable goods, alongside Internet of Things (IoT)-based smart storage solutions, the operational efficiency of supply chains can be greatly augmented. Furthermore, the establishment of decentralized distribution hubs plays a pivotal role in minimising waste, thus making a substantial contribution to the global sustainability agenda. Managers can begin with pilot-scale cold storage or shared logistics models, while local authorities can facilitate public–private partnerships to co-invest in rural logistics infrastructure.

Secondly, fostering collaboration among stakeholders need to be done in parallel to improve the weakness of Vietnamese agri-startups. As discussed above, the imbalance between local goals (i.e., regarding the businesses, such as storage) and global goals (i.e., regarding the whole supply chain, such as distribution) are the main causes of those weaknesses; collaboration is its key solution. Establishing clear and effective communication channels, coupled with the creation of digital platforms that facilitate real-time interaction, is essential for vibrant stakeholder engagement. Additionally, building partnerships with non-governmental organisations, government bodies, and research institutions creates robust and sustainable networks necessary for addressing complex challenges and driving collective progress. In this sense, policymakers can formalise multi-stakeholder innovation clusters, whereas startup managers should prioritise formal agreements and shared performance metrics to strengthen long-term collaboration.

Thirdly, the agri-startups should continuously optimize their operational processes to reduce the costs, improve efficiency and productivity, therefore improving the three pillars of Industry 5.0. The adoption of cutting-edge precision farming technologies, sophisticated supply chain management software, and comprehensive marketing strategies can serve as a transformative solution. These advancements not only streamline agricultural practices but also align emerging markets with the forward-thinking principles of Industry 5.0, fostering greater productivity and innovation. Practical implementations may include phased digital adoption plans, standard operating procedures for data management, and targeted training programmes supported by government innovation funds.

Author contributions

Conceptualization: HH. Data curation: HH. Formal analysis: HH. Funding acquisition: HH. Investigation: HH. Project administration: HN. Supervision: TN, HN. Validation: HN, TN. Writing – original draft: HN, HH, TN. Writing – review and editing: HH, HN, TN.

Artificial Intelligence (AI) use

The authors accept full responsibility for the content of the manuscript, including the disclosure of any use of AI. No AI tools were used in the preparation of this manuscript.

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References

Akhtar P, Tse YK, Khan Z, Rao-Nicholson R (2016) Data-driven and adaptive leadership contributing to sustainability: global agri-food supply chains connected with emerging markets. International Journal of Production Economics 181(B): 392–401. https://doi.org/10.1016/j.ijpe.2015.11.013

Carter CR, Rogers DS, Choi TY (2015) Toward the Theory of the Supply Chain. Journal of Supply Chain Management 51: 89–97. https://doi.org/10.1111/jscm.12073

Chi M, Huang R, George JF (2020) Collaboration in demand-driven supply chain: Based on a perspective of governance and IT-business strategic alignment. International Journal of Information Management 52: 102062. https://doi.org/10.1016/j.ijinfomgt.2019.102062

Corallo A, Latino ME, Menegoli M, Signore F (2024) Digital Technologies for Sustainable Development of Agri-Food: Implementation Guidelines Toward Industry 5.0. IEEE Transactions on Engineering Management 71: 10699–10715. https://doi.org/10.1109/tem.2024.3403251

Correia E, Carvalho H, Azevedo SG, Govindan K (2017) Maturity Models in Supply Chain Sustainability: A Systematic Literature Review. Sustainability 9(1): 64. https://doi.org/10.3390/su9010064

Correia E, Garrido-Azevedo S, Carvalho H (2023) Supply Chain Sustainability: A Model to Assess the Maturity Level. Systems 11(2): 98. https://doi.org/10.3390/systems11020098

Edgeman R, Eskildsen J (2014) Modeling and assessing sustainable enterprise excellence. Business Strategy and the Environment 23(3): 173–187. https://doi.org/10.4018/978-1-4666-5202-6.ch218

Elkington J (1997) Cannibals with Forks: The Triple Bottom Line of 21st Century Business. Capstone, Oxford. https://doi.org/10.1002/tqem.3310080106

Esfahbodi A, Zhang Y, Watson G, Zhang T (2017) Sustainable supply chain management in emerging economies: Trade-offs between environmental and cost performance. International Journal of Production Economics 181: 350–366. https://doi.org/10.1016/j.ijpe.2016.02.013

Fares N, Anass C, Shardeo V, Garza-Reyes JA (2025) Supply chain management in the Industry 5.0 era: strategic implications. Benchmarking: An International Journal 1–29. https://doi.org/10.1108/bij-12-2024-1136

Fu H, Zhao C, Cheng C, Ma M (2020) Blockchain-based agri-food supply chain management: Case study in China. International Food and Agribusiness Management Review 23(5): 737–752. https://doi.org/10.22434/ifamr2019.0152

Geng R, Mansouri SA, Aktas E (2017) The relationship between green supply chain management and performance: A meta-analysis of empirical evidence in Asian emerging economies. International Journal of production Economics 183(A): 245–258. https://doi.org/10.1016/j.ijpe.2016.10.008

Ghazinoori S, Olfat L, Soofi JB, Ahadi R (2020) Investigating the Organic Agricultural Products Supply Chain in Iran. International Journal of Agricultural Management and Development 10(1): 71–85.

Govindan K, Azevedo SG, Carvalho H, Cruz-Machado V (2014) Impact of supply chain management practices on sustainability. Journal of Cleaner Production 85: 212–225. https://doi.org/10.1016/j.jclepro.2014.05.068

Hammad M, Ali H, Hussain G, Wang X (2026) Industry 5.0: The Human-Centric Future of Industry. Springer Cham, Switzerland. https://doi.org/10.1007/978-3-032-12622-1

Hingne A, Sheikh A, Agarwal V, Adhia V (2021) Potential impact of corporate climate action in India. World Resources Institute. https://doi.org/10.46830/wriwp.19.00067

Ho T, Kumar A, Shiwakoti N (2020) Supply chain collaboration and performance: an empirical study of maturity model. Discover Applied Sciences 2: 726. https://doi.org/10.1007/s42452-020-2468-y

Hohagen S, Wilkens U (2025) How to measure digital maturity in agriculture? Conceptual outline, instrument development and measurement results from German farms. International Food and Agribusiness Management Review 28(5): 927–947. https://doi.org/10.22434/ifamr.1027

Ho D, Kumar A, Shiwakoti N (2016) Maturity model for supply chain collaboration: CMMI approach. In 2016 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), 845–849. Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/ieem.2016.7797996

Ho TDA, Dang TC, Tran VH, Trinh TH, Banh TT (2023) Factors affecting collaboration in the agricultural supply chain: A case study in the North Central region of Vietnam. Cogent Business & Management 10(3). https://doi.org/10.1080/23311975.2023.2256072

Hynds EJ, Brandt V, Burek S, Jager W, Knox P, Parker JP, et al. (2014) A maturity model for sustainability in new product development. Research-Technology Management 57(1): 50–57. https://doi.org/10.5437/08956308x5701143

Kim WS, Lee WS, Kim YJ (2020) A Review of the Applications of the Internet of Things (IoT) for Agricultural Automation. Journal of Biosystems Engineering 45: 385–400. https://doi.org/10.1007/s42853-020-00078-3

Lahti M, Shamsuzzoha AHM, Helo P (2009) Developing a maturity model for Supply Chain Management. International Journal of Logistics Systems and Management 5(6): 654–678. https://doi.org/10.1504/ijlsm.2009.024796

Manfredi E, Capik P (2022) A case of trust-building in the supply chain: Emerging economies perspective. Strategic Change 31(1): 147–160. https://doi.org/10.1002/jsc.2488

Mani V, Gunasekaran A, Papadopoulos T, Hazen B, Dubey R (2016) Supply chain social sustainability for developing nations: Evidence from India. Resources, Conservation and Recycling 111: 42–52. https://doi.org/10.1016/j.resconrec.2016.04.003

Mastos T, Gotzamani K (2022) Sustainable Supply Chain Management in the Food Industry: A Conceptual Model from a Literature Review and a Case Study. Foods 11(15): 2295. https://doi.org/10.3390/foods11152295

Ngo T, Nguyen H-D, Ho H, Nguyen V-K, Dao TT T, Nguyen HT H (2021) Assessing the important factors of sustainable agriculture development: An Indicateurs de Durabilité des Exploitations Agricoles-Analytic Hierarchy Process study in the northern region of Vietnam. Sustainable Development 29(2): 327–338. https://doi.org/10.1002/sd.2148

Nolan RL, Gibson C F (1974) Managing the four stages of EDP growth. Harvard Business Review 52(1): 76–88.

Hansali O, Elrhanimi S, Abbadi LE (2022) Supply chain maturity models: a comparative review. LogForum 18(4): 435–450. https://doi.org/10.17270/j.log.2022.751

Pagell M, Wu Z (2009) Building a more complete theory of sustainable supply chain management using case studies of 10 exemplars. Journal of Supply Chain Management 45(2): 37–56. https://doi.org/10.1111/j.1745-493x.2009.03162.x

Paulraj A, Chen IJ, Flynn J (2006) Levels of strategic purchasing: Impact on supply integration and performance. Journal of Purchasing and Supply Management 12(3): 107–122. https://doi.org/10.1016/j.pursup.2006.08.002

Qian X, Olsen TL (2019) Financial and risk management in agricultural cooperatives with application to the milk industry in New Zealand. International Journal of Production Research 59(19): 5913–5943. https://doi.org/10.1080/00207543.2020.1797204

Rahim MA, Rokonuzzaman M, Alqumsan AA, Arogbonlo A, Islam MZ, Trinh H, Islam MS (2025) An intelligent and secure internet of robotic things: A review and conceptual framework. Internet of Things 33: 101684. https://doi.org/10.1016/j.iot.2025.101684

Rajeev A, Pati R K, Padhi SS, Govindan K (2017) Evolution of sustainability in supply chain management: A literature review. Journal of Cleaner Production 162: 299–314. https://doi.org/10.1016/j.jclepro.2017.05.026

Rana J, Daultani Y, Goswami M, Kumar S (2025) Exploring the Impact of Supply Chain Digital Transformation on Supply Chain Performance: An Empirical Investigation. Business Strategy and the Environment 34: 3497–3521. https://doi.org/10.1002/bse.4157

Saaty TL (2004) Decision making – the Analytic Hierarchy and Network Processes (AHP/ANP). Journal of Systems Science and Systems Engineering 13(1): 1–35. https://doi.org/10.1007/s11518-006-0151-5

Sánchez-Flores RB, Cruz-Sotelo SE, Ojeda-Benitez S, Ramírez-Barreto ME (2020) Sustainable Supply Chain Management—A Literature Review on Emerging Economies. Sustainability 12(17): 6972. https://doi.org/10.3390/su12176972

Senna PP, Barros AC, Bonnin Roca J, Azevedo A (2023) Development of a digital maturity model for Industry 4.0 based on the technology–organization–environment framework. Computers & Industrial Engineering 185: 109645. https://doi.org/10.1016/j.cie.2023.109645

Seuring S, Müller M (2008) From a literature review to a conceptual framework for sustainable supply chain management. Journal of Cleaner Production 16(15): 1699–1710. https://doi.org/10.1016/j.jclepro.2008.04.020

Singh KA, Patra F, Ghosh T, Mahnot NK, Dutta H, Duary RK (2025) Advancing food systems with industry 5.0: A systematic review of smart technologies, sustainability, and resource optimization. Sustainable Futures 9: 100694. https://doi.org/10.1016/j.sftr.2025.100694

Sharma J, Tyagi M, Bhardwaj A (2021) Exploration of COVID-19 impact on the dimensions of food safety and security: a perspective of societal issues with relief measures. Journal of Agribusiness in Developing and Emerging Economies 11(5): 452–471. https://doi.org/10.1108/jadee-09-2020-0194

Tseng M-L, Chiu ASF (2013) Evaluating firm's green supply chain management in linguistic preferences. Journal of Cleaner Production 40: 22–31. https://doi.org/10.1016/j.jclepro.2010.08.007

Villar C, Mesa RJ, Plà Barber J (2020) A meta-analysis of export spillovers from FDI: advanced vs emerging markets. International Journal of Emerging Markets 15(5): 991–1010. https://doi.org/10.1108/ijoem-07-2019-0526

Wieland A (2016) Managing the Unknown: How We Should Tackle Risk in Global Supply Chains. The Global Logistics Magazine 4(1): 36–37.

Yawar SA, Seuring S (2017) Management of Social Issues in Supply Chains: A Literature Review Exploring Social Issues, Actions and Performance Outcomes. Journal of Business Ethics 141: 621–643. https://doi.org/10.1007/s10551-015-2719-9

Yildirim A, Clarysse B, Wright M (2022) The impact of institutional voids and ecosystem logics in the spread of ecosystems in emerging economies. Industry and Innovation 29(5): 649–671. https://doi.org/10.1080/13662716.2021.2007760

Zhang N, Wang M, Wang N (2002) Precision agriculture – a worldwide overview. Computers and Electronics in Agriculture 36(2–3): 113–132. https://doi.org/10.1016/s0168-1699(02)00096-0

Zhou W, Chong A, Zhen C, Bao H (2018) E-supply chain integration adoption: Examination of buyer–supplier relationships. Journal of Computer Information Systems 58(1): 58–65. https://doi.org/10.1080/08874417.2016.1189304

Zhu Q, Sarkis J, Lai K (2007) Green supply chain management: Pressures, practices and performance within the Chinese automobile industry. Journal of Cleaner Production 15(11–12): 1041–1052. https://doi.org/10.1016/j.jclepro.2006.05.021

Zhu Q, Sarkis J, Lai K (2008) Confirmation of a measurement model for green supply chain management practices implementation. International Journal of Production Economics 111(2): 261–273. https://doi.org/10.1016/j.ijpe.2006.11.029