






## **Planning Sustainable Smallholder Rubber Supply Chains: Green Intellectual Capital, Green Transformational Leadership, Digital Transformation, and Sustainable Value Co-Creation**

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### **ABSTRACT**

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This study investigates how green intellectual capital (GIC), green transformational leadership (GTL), and digital transformation (DT) shape sustainable value co-creation (SVC) in a smallholder-dominated rubber supply chain in a developing country. Drawing on the Resource-Based View, Dynamic Capabilities Theory (DCT), and Service-Dominant Logic (SDL), an integrated model was developed and empirically tested with survey data from 129 farmers, traders, and processors in South Sumatra, Indonesia. Partial Least Squares Structural Equation Modeling (PLS-SEM) was applied to assess the measurement and structural models and to evaluate their predictive performance. The results indicate that GIC, GTL, and DT have significant positive effects on SVC. In contrast, dynamic capabilities (DC) have positive but statistically insignificant effects, suggesting limited maturity in this context. Overall, the model demonstrates satisfactory reliability, validity, and predictive relevance. These findings suggest that strengthening green knowledge assets, leadership development, and inclusive digital infrastructure can enhance collaborative sustainability practices in smallholder rubber systems. This study provides planning and policy implications for governments, cooperatives, and supply chain leaders seeking to design SDG-oriented programs that simultaneously improve environmental performance and support more inclusive rural development. By framing SVC as a response to traceability gaps, information asymmetry, fragmented intermediation, and weak cooperative coordination, this study provides a context-sensitive explanation of sustainability planning in smallholder rubber supply chains.

## **1. INTRODUCTION**

The agricultural sector plays a pivotal role in the economies and livelihoods of developing countries, particularly in rural regions where smallholder farmers dominate production [1-3]. In Indonesia, smallholder rubber farming remains a critical source of income for rural households, yet it is increasingly exposed to market volatility, environmental degradation, and social vulnerabilities [4-6]. These intertwined challenges hinder progress towards several Sustainable Development Goals (SDGs), including poverty reduction, decent work and economic growth, responsible consumption and production, climate action, and sustainable rural communities [1]. At the same time, global buyers and emerging regulatory frameworks are raising expectations for traceability, environmental performance, and social responsibility along agricultural supply chains, placing new pressures on smallholder-dominated systems to improve their planning and management practices [7-9].

Fragmented relationships among farmers, intermediaries,

and processors limit access to information and technology, and weak environmental management capabilities are typically characteristic of smallholder rubber supply chains [10-12]. This fragmentation undermines the coordination of production, quality management, and environmental practices, making it challenging to design and implement coherent, sustainable supply chain strategies. Although the literature on sustainable supply chain management has expanded rapidly, much of it has focused on large firms, export-oriented agribusinesses, or manufacturing systems, while offering relatively limited micro-level evidence on how sustainability is co-created among dispersed smallholder actors. Existing studies often concentrate on formal certification schemes, upstream-downstream governance, or specific environmental interventions, rather than on the underlying relational and knowledge-based mechanisms that enable collaborative sustainability in smallholder contexts [13, 14].

Three interrelated enablers are particularly relevant for planning sustainable smallholder rubber supply chains. First, green intellectual capital (GIC) reflects the stock of

environmental knowledge, skills, and routines embedded in individuals, organizations, and their relationships. It shapes how actors recognize environmental issues, generate green innovations, and integrate sustainability into everyday decisions and coordination processes [15]. Second, green transformational leadership (GTL) encompasses the ability of leaders to articulate a compelling green vision, inspire followers to embrace sustainability goals, and support behavioral change through coaching, role modeling, and empowerment. Such leadership is crucial in smallholder-dominated networks where formal structures and incentives are often weak, and relational influence plays a central role [16]. Third, digital transformation (DT) is reshaping how information is shared, transactions are coordinated, and performance is monitored across agricultural value chains. Digital tools can reduce information asymmetries, enhance transparency, and facilitate more inclusive participation of smallholders in planning and decision-making [17, 18].

Despite these developments, an important gap remains in explaining why sustainability-oriented coordination failures persist in smallholder rubber supply chains. In South Sumatra, sustainability planning is constrained not only by environmental risks and market pressures, but also by fragmented intermediation, information asymmetry, weak traceability, uneven environmental practices in latex handling and processing, and limited cooperative coordination among farmers, traders, and processors. Existing studies rarely explain how these coordination problems are shaped by the interaction of knowledge-based resources, leadership, digital connectivity, and adaptive capacity at the micro level. As a result, the literature still offers limited guidance on why some smallholder networks are better able than others to translate sustainability pressures into shared practices and co-created outcomes. In particular, the role of dynamic capabilities (DC) remains underexplored in such settings, where capabilities are likely to be uneven, actor-specific, and still emergent rather than fully institutionalized [19-21].

This study addresses these gaps by proposing and empirically testing an integrated model of sustainable value co-creation (SVC) in smallholder rubber supply chains in South Sumatra, Indonesia. Drawing on the Resource-Based View (RBV), Dynamic Capabilities Theory (DCT), and Service-Dominant Logic (SDL), the model links GIC, GTL, DT, and DC to SVC among farmers, intermediaries, and processors [22-24]. Survey data from 129 supply chain actors are analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) to assess both the measurement and structural models and to evaluate the predictive performance of the proposed framework [25].

This study is novel not merely because it applies an established model to a new empirical setting, but because it reframes SVC as a response to persistent coordination failures in a fragmented smallholder rubber supply chain. Specifically, the study brings together GIC, GTL, and DT as complementary enablers of coordination, while examining whether DC operates as a direct driver in a context where adaptive capacity is unevenly distributed across actors. In doing so, the study offers a more context-sensitive explanation of how sustainability-related value is co-created in smallholder rubber systems and why certain enabling mechanisms are more immediately consequential than others. Accordingly, the study addresses the following research questions:

1) How do GIC, GTL, and DT influence SVC in

smallholder rubber supply chains?

- 2) What is the role of DC in shaping SVC in this context?
- 3) How can these micro-level mechanisms inform SDG-oriented planning and policy strategies for smallholder-dominated rural supply chains?

The contributions of this paper are threefold. First, it extends the literature on sustainable supply chain management and agricultural development by providing micro-level evidence from a fragmented smallholder rubber supply chain, where sustainability outcomes depend on coordination across actors with unequal resources and capabilities. Second, it advances theory by moving beyond an additive use of RBV, DC, and SDL and by positioning SVC as the relational mechanism through which knowledge assets, leadership, and digital connectivity are translated into sustainability-oriented coordination. Third, it offers context-sensitive planning and policy implications for governments, cooperatives, and supply chain leaders by linking the empirical findings to traceability gaps, information asymmetry, fragmented intermediation, environmental management practices, and weak cooperative coordination in South Sumatra. The remainder of the paper is organized as follows: Section 2 reviews the relevant literature and theoretical foundations; Section 3 describes the research methodology; Section 4 presents the empirical results; Section 5 discusses the findings and their implications for planning and policy; and Section 6 concludes with limitations and directions for future research.

## 2. LITERATURE REVIEW

### 2.1 Sustainable development and planning in smallholder agricultural supply chains

Sustainable development in agricultural regions requires coordinated interventions that simultaneously address environmental protection, rural livelihoods, and institutional capacity [26, 27]. In smallholder-dominated supply chains, such as the rubber supply chain, governance structures are often fragmented, marketing channels are long, and relationships between farmers, intermediaries, and processors are shaped by informal norms rather than formal contracts [28, 29]. These structural conditions create planning challenges for governments and development agencies seeking to align local practices with the SDGs, particularly SDG 8 (decent work and economic growth), SDG 9 (industry, innovation and infrastructure), SDG 12 (responsible consumption and production), and SDG 13 (climate action) [30].

Recent studies on sustainable agricultural supply chains highlight the importance of collaborative arrangements, shared information, and joint environmental initiatives to overcome structural barriers in smallholder systems [31-33]. However, many interventions remain focused on technical or financial solutions, while neglecting the underlying knowledge assets, leadership behaviors, and digital infrastructures that enable actors to co-create sustainable value over time [28, 29]. This suggests the need for planning approaches that explicitly incorporate micro-level mechanisms, such as green knowledge sharing, inspirational leadership, and digital connectivity, into broader SDG-oriented development strategies for rural supply chains [34-38].

## 2.2 Integrated theoretical foundations: Resource-Based View, Dynamic Capabilities Theory, and Service-Dominant Logic

This study integrates the RBV, DCT, and SDL to conceptualize how smallholder rubber supply chains can be steered towards sustainable development. RBV posits that valuable, rare, inimitable, and non-substitutable resources, such as environmental knowledge, organizational routines, and relational assets, are critical for achieving sustained competitive advantage. In the context of sustainable development, green-oriented knowledge and relational capital become key resources for designing and implementing environmentally responsible practices in rural supply chains [39, 40].

DCT extends RBV by emphasizing the ability of organizations and networks to integrate, build, and reconfigure resources in response to changing environments [41]. For smallholder rubber systems facing new sustainability regulations, market volatility, and climate risks, DC reflect actors' capacity to experiment, learn, and adapt their practices in line with SDG-oriented requirements [42].

SDL, in turn, conceptualizes value as being co-created through interactions among multiple actors who integrate resources and apply competencies for mutual benefit [43]. Rather than viewing value as embedded in products or transactions, SDL emphasizes relational process, joint problem-solving, and shared institutional arrangements. In the context of this study, SVC refers to the collaborative mechanism through which farmers, traders, and processors jointly generate economic, social, and environmental value aligned with sustainable development and planning goals.

By combining these three perspectives, the study proposes a clearer explanatory mechanism for SVC in smallholder rubber supply chains. RBV explains why green knowledge assets, relational capital, and digital resources matter as strategic inputs; SDL explains how these inputs are activated through interaction, joint problem-solving, and shared planning among farmers, intermediaries, and processors; and DCT explains whether and to what extent actors are able to sense sustainability-related pressures, seize responses, and reconfigure practices over time. In this logic, GIC, GTL, and DT are not treated as isolated predictors, but as coordination-enabling conditions whose effects are realized through SVC, whereas DC represent the higher-order adaptive capacity that may remain uneven or underdeveloped in fragmented smallholder networks.

## 2.3 Green intellectual capital and sustainable value co-creation

GIC refers to the stock of green human, structural, and relational capital that supports an organization's environmental management and innovation efforts [44]. Green human capital encompasses employees' ecological knowledge, skills, and attitudes; green structural capital comprises organizational routines, procedures, and information systems that embed environmental considerations; and green relational capital reflects trust-based relationships with external stakeholders, such as suppliers, customers, and communities, that facilitate joint environmental initiatives [36].

In smallholder rubber supply chains, GIC manifests in collective know-how for environmentally friendly tapping and coagulation, shared waste management procedures, and

collaborative initiatives among farmer groups, cooperatives, and processors to meet sustainability standards. When these knowledge assets are developed and shared among actors, they provide a foundation for SVC by enabling joint problem-solving, mutual learning, and collaborative experimentation with greener practices. Prior studies have shown that GIC strengthens environmental performance, innovation, and collaborative sustainability practices in various sectors [15, 36, 44].

Accordingly, this study expects that higher levels of GIC within smallholder rubber networks will foster more intense and effective SVC among supply chain actors. Thus, the first hypothesis is formulated as:

**H1.** *GIC positively influences SVC.*

## 2.4 Green transformational leadership and sustainable value co-creation

GTL describes leaders who articulate an environmentally oriented vision, inspire followers to internalize green values, intellectually stimulate them to question unsustainable routines, and provide individualized consideration for pro-environmental initiatives. Such leaders play a critical role in creating a culture that supports sustainability, particularly in contexts where formal regulations and structures are weak. In smallholder supply chains, leadership may be exercised by farmer group heads, cooperative managers, processing firm supervisors, or local government officers who champion sustainable practices [16, 34].

Green transformational leaders can catalyze SVC by motivating actors to engage in joint environmental projects, facilitating dialogue across smallholders, traders, and processors, and mobilizing resources for collective action. Empirical studies report that GTL enhances employees' pro-environmental behaviors, environmental innovation, and green organizational performance. In networked settings, it can also foster shared understanding and trust, which are essential for collaborative planning and implementation of sustainability initiatives [45, 46].

In the small rubber context, it is therefore expected that stronger GTL, across farmer groups, intermediaries, and processing firms, will be associated with more intensive SVC. This leads to the second hypothesis:

**H2.** *GTL positively influences SVC.*

## 2.5 Digital transformation and sustainable value co-creation

DT refers to the strategic integration of digital technologies into organizational and inter-organizational processes to create new forms of value and improve performance. In agricultural supply chains, digital tools such as mobile communication, digital traceability systems, cloud-based platforms, and data analytics can reduce information asymmetries, increase transparency, and support more efficient and sustainable coordination between actors. For smallholder rubber systems, DT may involve using mobile applications for price information, digital records of latex deliveries, or traceability platforms that document environmental compliance [47, 48].

From an RBV and SDL perspective, digital resources and capabilities constitute key enablers of SVC. Digital tools allow farmers, traders, and processors to share information about quality, environmental practices, and market conditions in real time, thereby facilitating joint decision-making and

collaborative problem-solving. They also enable supply chain actors to participate in new sustainability-oriented schemes, such as low-carbon supply chain initiatives or deforestation-free sourcing programs, which rely heavily on data sharing and verification. Prior research shows that DT can enhance supply chain integration, innovation, and sustainability outcomes when combined with appropriate organizational capabilities [49, 50].

In this study, DT is expected to strengthen SVC by improving connectivity and information exchange among smallholder rubber actors and by enabling more inclusive participation in sustainability initiatives. Thus, the following hypothesis is proposed:

**H3.** *DT positively influences SVC.*

**2.6 Dynamic capabilities and sustainable value co-creation**

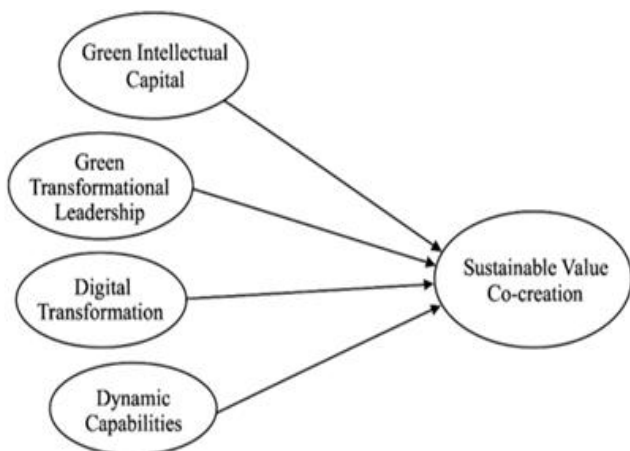
DC capture the ability of organizations and networks to sense opportunities and threats, seize them through appropriate investments and partnerships, and reconfigure resources and routines to sustain competitiveness in changing environments [23, 51, 52]. In smallholder rubber supply chains, DC are reflected in the capacity of farmer groups, cooperatives, intermediaries, and processors to reinterpret sustainability demands, experiment with cleaner technologies, adjust procurement and marketing arrangements, and institutionalize new green practices over time.

From a sustainable development and planning perspective, DC are necessary to move beyond isolated projects towards more durable structural change. When DC are strong, supply chain actors are better able to translate GIC, leadership, and digital resources into new configurations of practices and relationships that support SVC. Existing studies suggest that DC facilitate environmental innovation, strategic renewal, and collaborative responses to sustainability challenges [53-56].

Accordingly, this study posits that higher levels of DC within the smallholder rubber network will enhance SVC by enabling actors to more effectively reconfigure their resources and relationships in line with SDG-oriented requirements. The fourth hypothesis is therefore stated as:

**H4.** *DC positively influence SVC.*

Based on the above discussion, the proposed research model links GIC, GTL, DT, and DC to SVC in smallholder supply chains, as illustrated in Figure 1.



**Figure 1.** Proposed research model

**3. MATERIAL AND METHOD**

**3.1 Research design and context**

This study adopted a quantitative, cross-sectional survey design to examine how GIC, GTL, DT, and DC influence SVC in smallholder rubber supply chains. The empirical context is South Sumatra, Indonesia, one of the central rubber-producing regions where smallholder farmers dominate production and interact with intermediaries and processors through largely informal arrangements. This context is particularly relevant to SDG-oriented planning because environmental risks, income vulnerability, and limited digital connectivity coexist with growing external pressure to achieve sustainable and traceable supply chains.

The conceptual model developed in this study links four exogenous constructs—GIC, GTL, DT, and DC—to a single endogenous construct, SVC. All constructs are specified as reflective latent variables and estimated using PLS-SEM, which is suitable for complex models, prediction-oriented research, and data that may deviate from multivariate normality.

**3.2 Population, sampling, and respondents**

The target population comprises key actors in the smallholder rubber supply chain in South Sumatra, namely smallholder farmers, intermediaries (collectors and traders), and processing firms. These actors are directly involved in latex production, collection, transport, and processing, and are therefore central to the planning and implementation of sustainability initiatives in the rubber sector.

A purposive sampling approach was used to ensure that respondents had sufficient experience and decision-making responsibility in rubber production and marketing. Eligible respondents had been involved in rubber-related activities for at least three years and participated in decisions related to production practices, marketing, or coordination with other supply chain actors. Potential respondents were identified through local cooperatives, farmer groups, and industry contacts.

An a priori power analysis using G\*Power [57], assuming a multiple regression model with four predictors, a medium effect size ( $f^2 = 0.15$ ), a 5% significance level, and 95% statistical power, indicated that a sample size within the range typically recommended for PLS-SEM would be sufficient to detect medium effects. The final sample consists of 129 respondents (farmers, intermediaries, and processors), which exceeds the minimum requirements suggested by the power analysis and standard PLS-SEM rules of thumb. It is therefore adequate for estimating the proposed model and conducting predictive assessments.

**3.3 Measurement of constructs**

All constructs were operationalized as reflective indicators measured using a structured questionnaire. Items for GIC, GTL, DT, DC, and SVC were adapted from established scales in the literature on GIC, green leadership, DT, and value co-creation, with wording adjusted to fit the smallholder rubber supply chain context.

Respondents were asked to indicate their agreement with each statement on a five-point Likert scale ranging from 1 = “strongly disagree” to 5 = “strongly agree”. GIC items

captured the extent of environmental knowledge, skills, shared routines, and relationship-based environmental collaboration within and across organizations. GTL items reflected the degree to which leaders articulated a green vision, inspired pro-environmental behavior, and encouraged collaborative environmental initiatives. DT items assessed the use of digital communication tools, information systems, and traceability-related practices in managing supply chain activities. DC items measured organizations' perceived ability to sense, seize, and reconfigure resources in response to sustainability-related changes. SVC items captured joint problem solving, shared planning, and collaborative initiatives that generate economic, social, and environmental value among farmers, intermediaries, and processors.

The questionnaire was drafted in Indonesian, the local language of the respondents. Before the primary survey, the instrument was pre-tested with a small group of practitioners and academics knowledgeable about rubber supply chains to assess the clarity, relevance, and cultural appropriateness of the items. Feedback from the pre-test was used to refine wording and layout.

### 3.4 Data collection procedures

Data were collected through face-to-face and assisted self-administered questionnaires in selected smallholder rubber-producing areas of South Sumatra for 3 months. Enumerators trained in research ethics and familiar with the local context approached eligible respondents through farmer groups, cooperatives, collection points, and processing facilities. After explaining the purpose of the study and assuring respondents of confidentiality, they were invited to complete the questionnaire. For participants with limited literacy or a preference for oral communication, enumerators read the questions aloud and recorded the responses.

Participation in the study was entirely voluntary. Respondents were informed that they could decline to answer any question or withdraw from the survey at any time without any consequences. No financial incentives were offered. The research protocol, including the questionnaire and recruitment procedures, was reviewed and approved by the Institutional Review Board of the Islamic University of Indonesia. All data were anonymized before analysis to protect the identity of participants and organizations.

### 3.5 Data analysis procedures

PLS-SEM was employed to estimate the measurement and structural models using SmartPLS version 4.1.1.4. This approach was chosen because it is appropriate for prediction-oriented studies, can handle complex models with multiple latent constructs and indicators, and imposes relatively few distributional assumptions on the data. The analysis followed the recommended two-step procedure in which the measurement model was assessed before the structural model [25, 58].

First, the measurement model was evaluated using indicator loadings, internal consistency reliability, convergent validity, and discriminant validity. Indicator reliability was assessed through outer loadings, internal consistency reliability through Cronbach's alpha,  $\rho_A$ , and composite reliability, and convergent validity through the average variance extracted (AVE). Discriminant validity was examined using both the Fornell-Larcker criterion and the heterotrait-monotrait ratio

(HTMT). In addition, indicator-level collinearity was assessed using the Variance Inflation Factor (VIF) values. Detailed outer loadings, VIF values, and item-retention decisions are reported in Table A1. During the indicator purification stage, all initial outer loadings were examined to assess indicator reliability. Indicators with loadings below 0.70 were evaluated for potential removal, particularly when their deletion improved composite reliability, AVE, and the overall measurement quality of the construct. Indicators with negative loadings were removed because they were inconsistent with the theoretical direction of the construct. After the purification process, the model was re-estimated and only indicators with satisfactory loadings, acceptable VIF values, and adequate theoretical relevance were retained. The initial outer loadings and deletion decisions are reported in Table A2, while the final retained indicators are reported in Table A1.

Second, the structural model was evaluated by examining path coefficients, their significance levels, the coefficient of determination ( $R^2$ ) for SVC, effect sizes ( $f^2$ ), and predictive relevance. Bootstrapping was performed using 5,000 subsamples, with a two-tailed test, and the percentile bootstrap confidence interval method was used to assess the significance of the hypothesized relationships. Out-of-sample predictive power was assessed using PLSpredict in SmartPLS 4, with predictive performance evaluated using  $Q^2_{predict}$  values and by comparing PLS-SEM prediction errors with those of benchmark models at the indicator level. Discriminant validity was primarily assessed using the HTMT ratio and the Fornell-Larcker criterion.

To reduce common method bias, several procedural remedies were implemented, including assuring respondents of anonymity, separating construct blocks in the questionnaire, and randomizing item order where appropriate. All items were measured on a five-point Likert scale, and the wording was refined during pre-testing to improve clarity and reduce ambiguity among respondents. Statistically, collinearity diagnostics were also examined to ensure that collinearity did not pose a serious threat to the model estimation.

## 4. RESULTS

### 4.1 Sample characteristics

To contextualize the empirical analysis, this subsection summarises the demographic and occupational profile of the respondents. The main sample characteristics are reported in Table 1.

**Table 1.** Demographic profile of respondents

Variable	Distribution (n, %)
Gender	Male 96 (74.4); Female 33 (25.6)
Age (years)	≤ 30: 34 (26.4); 31–45: 57 (44.2); ≥ 46: 38 (29.4)
Education level	Primary/Junior High: 19 (14.7); Senior High School: 71 (55.0); Diploma/Bachelor: 35 (27.1); Master and above: 4 (3.1)
Occupation	Smallholder farmer: 73 (56.6); Trader/collector: 27 (20.9); Processing industry: 18 (14.0); Others (cooperatives, agencies, etc.): 11 (8.5)
Work experience (years)	< 5: 23 (17.8); 5–10: 44 (34.1); > 10: 62 (48.1)

Table 1 presents the demographic profile of the 129 respondents. The sample is predominantly male, with 96 respondents (74.4%) compared with 33 females (25.6%). Most respondents are in the productive age range of 31–45 years (44.2%), followed by those aged  $\geq 46$  years (29.4%) and  $\leq 30$  years (26.4%). In terms of education, more than half (55.0%) have completed senior high school. In comparison, 27.1% hold a diploma or bachelor's degree and 3.1% a master's degree or higher, indicating a basic educational capacity to engage with technical and managerial innovations. The majority of respondents are smallholder farmers (56.6%), with traders/collectors (20.9%), processing industry actors (14.0%), and other institutional actors such as cooperatives and agencies (8.5%) also represented. Nearly half of the respondents have more than 10 years of experience in the rubber sector (48.1%), suggesting that the sample comprises experienced actors closely involved in production, marketing, and processing.

#### 4.2 Measurement models assessment

The measurement model was evaluated in accordance with established PLS-SEM guidelines. All retained indicators exhibited satisfactory outer loadings on their respective constructs, indicating adequate indicator reliability. Composite reliability values for all constructs exceeded the recommended threshold of 0.70, while Cronbach's alpha values were generally acceptable, although some constructs were slightly below 0.70. The AVE for each construct was above 0.50, supporting convergent validity [25, 59].

**Table 2.** Reliability and convergent validity of constructs

	Cronbach's Alpha	rho_a	rho_c	AVE
DC	0.672	0.693	0.858	0.751
DT	0.709	0.762	0.87	0.771
GIC	0.647	0.666	0.848	0.737
GTL	0.714	0.715	0.84	0.637
SVC	0.812	0.813	0.869	0.57

Note: DC = dynamic capabilities; DT = digital transformation; GIC = green intellectual capital; GTL = green transformational leadership; SVC = sustainable value co-creation; AVE = average variance extracted.

As shown in Table 2, Cronbach's alpha values range from 0.647 for GIC to 0.812 for SVC. Although the alpha values for GIC and DC are slightly below the conventional threshold of 0.70, their composite reliability values exceed 0.70 and their AVE values are above 0.50. Therefore, the constructs still demonstrate acceptable internal consistency reliability and convergent validity. Composite reliability values range from 0.840 to 0.870, while AVE values range from 0.570 to 0.771.

Discriminant validity was further examined using the HTMT of correlation.

**Table 3.** Discriminant validity: Heterotrait-monotrait ratio (HTMT)

	DC	DT	GIC	GTL	SVC
DC					
DT	0.807				
GIC	0.813	0.679			
GTL	0.834	0.704	0.795		
SVC	0.764	0.731	0.873	0.788	

Note: DC = dynamic capabilities; DT = digital transformation; GIC = green intellectual capital; GTL = green transformational leadership; SVC = sustainable value co-creation.

As reported in Table 3, all HTMT values range from 0.679 to 0.873, which are below the conservative upper bound of 0.90. The highest HTMT value is observed between GIC and SVC (0.873), but it remains within acceptable limits. These results indicate that the constructs are empirically distinct and that discriminant validity is satisfactorily established. For transparency, the detailed indicator loadings and indicator-level VIF values are reported in Table A1. This additional reporting strengthens the transparency of the empirical assessment and aligns the analysis with current PLS-SEM reporting expectations [60–62].

**Table 4.** Discriminant validity: Fornell-Larcker criterion

	DC	DT	GIC	GTL	SVC
DC	<b>0.867</b>				
DT	0.564	<b>0.878</b>			
GIC	0.53	0.475	<b>0.858</b>		
GTL	0.585	0.508	0.538	<b>0.798</b>	
SVC	0.577	0.569	0.641	0.607	<b>0.755</b>

Note: DC = dynamic capabilities; DT = digital transformation; GIC = green intellectual capital; GTL = green transformational leadership; SVC = sustainable value co-creation.

As shown in Table 4, the square roots of the AVE values (diagonal elements) are greater than the corresponding inter-construct correlations in the duplicate rows and columns. For example, the square root of the AVE for SVC (0.755) is higher than its correlations with GIC (0.641), GTL (0.607), DT (0.569), and DC (0.577). This pattern holds across all constructs, indicating that each latent variable shares more variance with its indicators than with indicators of other constructs, thereby providing further evidence of satisfactory discriminant validity.

The final measurement model was obtained after the indicator purification process. As shown in Table A2, several indicators in the initial model had outer loadings below 0.70, while DC3 and DC4 showed negative loadings. These indicators were removed because they weakened indicator reliability or were inconsistent with the expected measurement direction. The model was then re-estimated, resulting in the final retained indicators reported in Table A1.

#### 4.3 Model fit

Before evaluating the structural relationships, the global model fit was assessed using the SRMR, d\_ULS, d\_G, chi-square, and NFI indices to determine whether the proposed model provides an acceptable representation of the data.

**Table 5.** Global model fit indices for the Partial Least Squares Structural Equation Modeling (PLS-SEM) model

	Saturated Model	Estimated Model
SRMR	0.081	0.081
d_ULS	0.683	0.683
d_G	0.325	0.325
Chi-square	258.613	258.613
NFI	0.653	0.653

Table 5 reports the global model fit indices for the saturated and estimated models. The SRMR value is 0.081 for both the saturated and estimated models, which is very close to the commonly suggested cut-off of 0.08 and therefore indicates an acceptable approximate model fit. The discrepancy measures d\_ULS (0.683) and d\_G (0.325) are identical across the

saturated and estimated models, suggesting no substantial overall discrepancies or apparent signs of model misspecification. The chi-square value is 258.613, and the NFI is 0.653, indicating moderate global fit. In line with current PLS-SEM guidelines, these indices are reported as complementary evidence. At the same time, the main evaluation of the model focuses on measurement and structural models, as well as on predictive assessment [25].

#### 4.4 Structural model assessment

Following the confirmation of the measurement model, the structural model was evaluated to determine how well the

proposed relationships among GIC, GTL, DT, DC, and SVC are supported by the data.

Table 6 presents the structural model results for SVC. GIC has the strongest positive effect on SVC ( $\beta = 0.341, t = 3.799, p < 0.001, f^2 = 0.164$ ), supporting H1. GTL also has a positive and significant effect on SVC ( $\beta = 0.235, t = 2.389, p = 0.017, f^2 = 0.070$ ), supporting H2. DT significantly influences SVC ( $\beta = 0.209, t = 2.641, p = 0.008, f^2 = 0.061$ ), supporting H3. In contrast, DC show a positive but statistically insignificant effect on SVC ( $\beta = 0.140, t = 1.305, p = 0.192, f^2 = 0.024$ ), thereby failing to support H4. The model explains 56.1% of the variance in SVC ( $R^2 = 0.561$ ).

**Table 6.** Structural model results for sustainable value co-creation (SVC)

H	Path	Std. Beta	T-Value	P-Value	f <sup>2</sup>	Decision
H1	GIC→SVC	0.341	3.799	< 0.001	0.164	Supp.
H2	GTL→SVC	0.235	2.389	0.017	0.070	Supp.
H3	DT→SVC	0.209	2.641	0.008	0.061	Supp.
H4	DC→SVC	0.140	1.305	0.192	0.024	Not supp.

Note: DC = dynamic capabilities; DT = digital transformation; GIC = green intellectual capital; GTL = green transformational leadership; SVC = sustainable value co-creation.  $R^2$  for SVC = 0.561.

#### 4.5 Predictive assessment using PLSpredict

To further evaluate the model’s out-of-sample predictive performance, PLSpredict was applied to the endogenous construct, namely, SVC. The predictive assessment was examined at both the construct and indicator levels. The construct-level result is presented in Table 7, while the detailed indicator-level results are provided in Table A3.

**Table 7.** Construct-level PLSpredict result for sustainable value co-creation (SVC)

	Q <sup>2</sup> predict	RMSE	MAE
SVC	0.509	0.712	0.538

Table 7 shows that SVC has a construct-level Q<sup>2</sup>predict value of 0.509, with RMSE = 0.712 and MAE = 0.538. Since the Q<sup>2</sup>predict value is positive, the model demonstrates satisfactory predictive relevance for the endogenous construct. At the indicator level, all SVC indicators also produced positive Q<sup>2</sup>predict values, ranging from 0.216 to 0.338. In addition, the PLS-SEM model produced lower RMSE and MAE values than the indicator-average benchmark for all indicators, and its prediction errors were generally lower than those of the linear model benchmark. Overall, these results confirm that the proposed model has adequate predictive relevance and satisfactory out-of-sample predictive capability.

## 5. DISCUSSION

### 5.1 Interpretation of key findings

The empirical results highlight the central role of GIC in enabling SVC in smallholder rubber supply chains. The significant and positive path from GIC to SVC suggests that environmental knowledge, shared routines, and collaborative relationships are crucial intangible resources for driving joint sustainability initiatives. In practical terms, when farmer groups, intermediaries, and processing firms possess a better understanding of environmentally friendly practices, have

procedures that institutionalize green behaviors, and maintain trust-based relationships with each other, they are more likely to engage in collective actions such as adopting safer coagulants, improving waste management, or meeting sustainability standards. This finding is consistent with the notion that knowledge-based assets constitute a core foundation for both competitive advantage and sustainable development in agrarian contexts [36, 63, 64].

The positive and significant effect of GTL on SVC underscores the importance of leadership behaviors in mobilizing collaborative sustainability efforts. Leaders who communicate a clear green vision, provide inspiration, and encourage participatory decision-making appear to foster a climate in which actors are willing to engage in joint environmental projects and share responsibility for improving supply chain practices. In smallholder networks characterized by informal governance and social norms, such leadership can compensate for weak formal institutions and help bridge the interests of farmers, traders, and processors. The result extends prior evidence on the influence of transformational leadership on pro-environmental behaviors by showing its relevance for cross-organizational collaboration in rural supply chains [65-67].

The significant relationship between DT and SVC indicates that digitalization is not merely a technical trend but a key enabler of collaborative sustainability. The adoption of digital communication tools, basic information systems, and simple traceability solutions appears to support more efficient information exchange, reduce asymmetries between actors, and increase transparency regarding quality and environmental performance. When information flows are more timely and reliable, actors are better positioned to co-plan harvesting, collection, processing, and environmental controls, which strengthens their capacity to co-create sustainable value. This finding reinforces the idea that digital infrastructures, even in relatively simple forms, can be strategically leveraged to support inclusive and environmentally responsible rural development [68-70].

In contrast, DC do not show a significant direct effect on SVC, despite exhibiting a positive coefficient. Rather than treating this result as a null finding with limited meaning, it

may indicate that DC in fragmented smallholder rubber networks do not operate as an immediate stand-alone driver of co-created sustainability outcomes. In such contexts, adaptive capacity is likely to be unevenly distributed across actors, weakly institutionalized, and dependent on intermediation structures, cooperative arrangements, and access to usable information. This helps explain why actors may possess emerging green knowledge, leadership support, or basic digital tools, yet still struggle to translate them into coordinated resource reconfiguration at the network level. The result, therefore, suggests that DC may be indirect, contingent, or actor-specific in this setting, becoming influential only when supported by stronger coordination mechanisms, more stable organizational arrangements, and sustained collective learning. In this sense, the non-significant direct path is theoretically informative because it reveals a capability gap between the emergence of sustainability-oriented enablers and the consolidation of higher-order adaptive capacity in smallholder supply chains [71-74].

Overall, the model explains a substantial proportion of the variance in SVC and demonstrates satisfactory predictive performance, indicating that the identified enablers capture important mechanisms shaping collaboration for sustainability in smallholder rubber supply chains. At the same time, the non-significant effect of DC and the still moderate effect sizes suggest considerable room to strengthen the underlying capacities of smallholder networks to support SDG-oriented transformation.

## 5.2 Contributions to sustainable development and planning

This study makes several contributions to the literature on sustainable development and planning. First, by focusing on a smallholder-dominated rubber supply chain in Indonesia, it addresses a context that has received relatively limited empirical attention compared to more formal and capital-intensive agri-food chains. The results provide micro-level evidence on how environmental knowledge, leadership, and digital practices influence collaborative mechanisms in a setting characterized by pronounced informal relationships, resource constraints, and environmental risks. This contextualized evidence enriches broader debates on how global sustainability agendas, such as the SDGs, intersect with the realities of rural production systems in the Global South.

Second, the study advances theory by integrating the RBV, DCT, and SDL into a single framework centered on SVC. Rather than treating sustainable development as the outcome of isolated technological interventions or top-down regulations, the proposed model conceptualizes it as emerging from the configuration of intangible resources and relational processes across multiple actors. GIC and digital resources are seen as strategic assets; GTL acts as a behavioral catalyst; and SVC represents the mechanism through which these elements are combined in practice to generate economic, social, and environmental value. This integrated perspective offers a more nuanced understanding of the micro-foundations of SDG-oriented planning in rural supply chains.

Third, the findings generate actionable insights for planners and policymakers tasked with designing sustainable development strategies for smallholder regions. By empirically demonstrating the importance of GIC, GTL, and DT, the study identifies specific capability domains that can be targeted through public programs, cooperative initiatives,

and private-sector partnerships. Rather than relying solely on infrastructure investment or regulatory enforcement, planning efforts can be directed toward building environmental knowledge, fostering leadership that champions sustainability, and expanding digital connectivity among smallholder actors. These directions align with the SDG targets related to decent work and economic growth (SDG 8), industry, innovation, and infrastructure (SDG 9), responsible consumption and production (SDG 12), climate action (SDG 13), and partnerships for the goals (SDG 17).

Finally, the limited direct role of DC highlights the challenges of implementing transformative change in fragmented smallholder networks. This nuance tempers overly optimistic assumptions about the ease with which smallholder systems can adapt to new sustainability requirements. It suggests that planning approaches need to account for the time and support required to develop higher-order capabilities. The study thus contributes to a more realistic and grounded understanding of the conditions under which SVC can effectively underpin long-term SDG-oriented transformation.

## 5.3 Policy and planning implications

The findings offer several implications for sustainable development planning in smallholder rubber regions. First, the strong effect of GIC suggests that planning interventions should not stop at generic training programs, but should specifically address the coordination problems that weaken sustainability implementation in South Sumatra, including inconsistent quality handling, limited diffusion of environmentally safer latex-processing practices, and weak knowledge sharing across farmers, collectors, cooperatives, and processors. Local governments and cooperatives can therefore prioritize structured peer-learning forums, practical guidance on cleaner processing routines, and simple shared operating procedures that reduce avoidable variation and improve collective environmental awareness.

Second, the significant role of GTL implies that leadership development should be targeted at the actual coordination nodes of the supply chain, particularly farmer-group leaders, cooperative managers, and intermediary coordinators who influence whether collective rules are followed in practice. In fragmented networks, leadership matters not only for motivation but also for aligning actors around traceability discipline, fairer information exchange, and more consistent environmental practices.

Third, DT should be translated into context-specific planning instruments rather than broad calls for digital infrastructure. In this supply chain, the most immediate priorities are low-cost systems that reduce information asymmetry and fragmented intermediation, such as digital recording of deliveries, simple traceability logs, shared price and quality information, and accessible communication channels linking upstream actors with cooperatives and processors. Such tools can strengthen transparency, support compliance with sustainability requirements, and improve the visibility of environmental and quality performance across transactions.

Fourth, the non-significant direct effect of DC indicates that long-term transformation cannot be assumed to emerge automatically once green knowledge or digital tools are introduced. In practice, adaptive capacity in smallholder rubber systems may depend on gradual institutional strengthening, repeated collective learning, and stronger

cooperative coordination. Planning strategies should therefore combine immediate coordination fixes with longer-term efforts to build organizational routines that allow actors to sense sustainability pressures, respond jointly, and progressively reconfigure their practices.

## 6. CONCLUSION

This study examined how GIC, GTL, DT, and DC influence SVC in smallholder rubber supply chains in South Sumatra, Indonesia. Drawing on the RBV, DCT, and SDL, an integrated model was tested using PLS-SEM with survey data from 129 farmers, intermediaries, and processors. The results show that GIC, GTL, and DT have significant positive effects on SVC. In contrast, DC exhibit a positive but non-significant direct effect. The model demonstrates satisfactory reliability, validity, and predictive relevance, indicating that these enablers provide a meaningful explanation of collaborative sustainability mechanisms in the context of smallholder rubber.

The findings contribute to the sustainable development and planning literature by reframing SVC as a key micro-level pathway for aligning smallholder-dominated supply chains with SDG-oriented development strategies. They underscore the importance of green knowledge assets, leadership behaviors, and digital infrastructure that enable actors to jointly design and implement more sustainable practices. Practically, the results suggest that SDG-oriented planning in smallholder rubber regions should prioritize programs that strengthen GIC through training and knowledge-sharing platforms, develop GTL among local actors, and invest in inclusive digital solutions that enhance connectivity, transparency, and participation. At the same time, the limited direct effect of DC suggests that new technologies or sustainability requirements must be accompanied by long-term efforts to build adaptive capacity and institutional support if smallholder rubber systems are to achieve more inclusive and environmentally responsible rural development.

### 6.1 Limitations and future research directions

This study has several limitations that open avenues for future research. First, it is based on cross-sectional survey data from a single province in Indonesia, which limits causal inference and generalisability; comparative and longitudinal studies across different smallholder commodity systems would help determine whether the observed coordination pattern is specific to rubber or more broadly characteristic of fragmented rural supply chains. Second, the analysis relies on perceptual measures and focuses on micro-level collaboration rather than direct environmental or socio-economic indicators. Future research could therefore combine survey data with objective indicators such as traceability performance, environmental management practices, processing quality consistency, or other operational sustainability metrics. Third, DC were modeled only as direct predictors and were not significant, suggesting that future studies should examine whether they operate indirectly, contingently, or differently across actor groups within the supply chain. Finally, the model concentrates on internal supply chain actors and does not explicitly incorporate downstream buyers, financial institutions, or public agencies, even though these actors may shape information flows, compliance pressures, and

sustainability incentives in important ways.

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## NOMENCLATURE

### Greek symbols

- $\alpha$  Cronbach's alpha (internal consistency reliability)  
 $\beta$  standardized path coefficient  
 $\rho$ -A composite reliability rho A  
 $\rho$ -C composite reliability rho C

### Subscripts

- $f^2$  effect size (local effect of an exogenous construct)  
 $Q^2$  predictive relevance metric from PLSpredict

## APPENDIX

Table A1 reports the outer loadings, indicator-level VIF values, and retention decisions for the final measurement model. All retained indicators show acceptable outer loadings, ranging from 0.735 to 0.919. The VIF values range from 1.291 to 1.921, indicating that collinearity is not a serious concern.

**Table A1.** Final indicator loadings, collinearity statistics, and retention decisions

Construct	Indicator	Outer Loading	VIF	Status
GIC	GIC3	0.890	1.296	Retained
GIC	GIC5	0.826	1.296	Retained
GTL	GTL2	0.813	1.468	Retained
GTL	GTL3	0.821	1.517	Retained
GTL	GTL5	0.758	1.291	Retained
DT	DT2	0.919	1.433	Retained
DT	DT3	0.835	1.433	Retained
DC	DC1	0.897	1.344	Retained
DC	DC2	0.835	1.344	Retained
SVC	SVC1	0.758	1.609	Retained
SVC	SVC2	0.788	1.921	Retained

SVC	SVC3	0.735	1.757	Retained
SVC	SVC6	0.739	1.521	Retained
SVC	SVC7	0.756	1.551	Retained

Note: DC = dynamic capabilities; DT = digital transformation; GIC = green intellectual capital; GTL = green transformational leadership; SVC = sustainable value co-creation; VIF = Variance Inflation Factor.

**Table A2.** Initial outer loadings and item deletion decisions

Construct	Indicator	Initial Outer Loading	Decision	Justification
GIC	GIC1	0.617	Deleted	Loading below 0.70 and weaker contribution to construct validity
GIC	GIC2	0.636	Deleted	Loading below 0.70 and removed during indicator purification
GIC	GIC3	0.751	Retained	Loading above 0.70 and conceptually relevant
GIC	GIC4	0.689	Deleted	Borderline loading; deletion improved final measurement quality
GIC	GIC5	0.726	Retained	Loading above 0.70 and conceptually relevant
GIC	GIC6	0.691	Deleted	Borderline loading; weaker contribution than retained indicators
GIC	GIC7	0.681	Deleted	Borderline loading; removed to improve convergent validity
GTL	GTL1	0.628	Deleted	Loading below 0.70
GTL	GTL2	0.747	Retained	Loading above 0.70
GTL	GTL3	0.723	Retained	Loading above 0.70
GTL	GTL4	0.699	Deleted	Borderline loading; removed during purification
GTL	GTL5	0.718	Retained	Loading above 0.70
GTL	GTL6	0.600	Deleted	Weak loading
DT	DT1	0.691	Deleted	Borderline loading
DT	DT2	0.806	Retained	Strong loading
DT	DT3	0.754	Retained	Loading above 0.70
DT	DT4	0.685	Deleted	Borderline loading
DC	DC1	0.880	Retained	Strong loading
DC	DC2	0.836	Retained	Strong loading
DC	DC3	-0.241	Deleted	Negative loading; inconsistent with construct direction
DC	DC4	-0.084	Deleted	Negative loading; inconsistent with construct direction
SVC	SVC1	0.719	Retained	Loading above 0.70
SVC	SVC2	0.740	Retained	Loading above 0.70
SVC	SVC3	0.745	Retained	Loading above 0.70
SVC	SVC4	0.682	Deleted	Borderline loading
SVC	SVC5	0.690	Deleted	Borderline loading
SVC	SVC6	0.718	Retained	Loading above 0.70
SVC	SVC7	0.720	Retained	Loading above 0.70
SVC	SVC8	0.661	Deleted	Loading below 0.70

Note: DC = dynamic capabilities; DT = digital transformation; GIC = green intellectual capital; GTL = green transformational leadership; SVC = sustainable value co-creation.

**Table A3.** Indicator-level PLSpredict results for sustainable value co-creation (SVC) indicators

Indicator	Q <sup>2</sup> predict	PLS-SEM_RMSE	PLS-SEM_MAE	LM_RMSE	LM_MAE	IA_RMSE	IA_MAE
SVC1	0.293	0.686	0.534	0.711	0.536	0.815	0.666
SVC2	0.254	0.673	0.546	0.695	0.577	0.780	0.684
SVC3	0.216	0.695	0.552	0.724	0.572	0.785	0.661
SVC6	0.338	0.579	0.450	0.605	0.455	0.711	0.545
SVC7	0.320	0.548	0.456	0.568	0.461	0.665	0.564