CarakaTani
Journal of Sustainable Agriculture
ISSN 2613-9456 (Print) 2599-2570 (Online)

Caraka Tani: Journal of Sustainable Agriculture, 41(1), 66-92, 2026
URL: https://jurnal.uns.ac.id/carakatani/article/view/100400
DOI: http://dx.doi.org/10.20961/carakatani.v41i1.100400

Beef Self-Sufficiency and Oil Palm Sustainability: Developing a Cattle-Oil Palm Integration System in Indonesia

Daeva Mubarika Raisa[1], Sitti Nurani Sirajuddin[2], Jasmal Ahmari Syamsu[3], Muhammad Arsyad[4*], Lellah Rahim[5], Musran Munizu[6], Muhammad Hatta Jamil[4], Abd. Haris Bahrun[7], Abdel Razzaq Mohammad Al-Tawaha[8], Budiman Nohong[3] and Siti Nurlaelah[2]

[1]Study Program of Agribusiness, Faculty of Agriculture, Mataram University, Mataram, Indonesia; [2]Department of Social Economics and Animal Science, Faculty of Animal Science, Hasanuddin University, Makassar, Indonesia; [3]Department of Animal Nutrition and Feed Science, Faculty of Animal Science, Hasanuddin University, Makassar, Indonesia; [4]Department of Agricultural Socio-economics, Faculty of Agriculture, Hasanuddin University, Makassar, Indonesia; [5]Department of Production Animal Science, Faculty of Animal Science, Hasanuddin University, Makassar, Indonesia; [6]Study Program of Management, Faculty of Economics and Business, Hasanuddin University, Makassar, Indonesia; [7]Department of Agrotechnology, Faculty of Agriculture, Hasanuddin University, Makassar, Indonesia; [8]National Agricultural Research Center (NARC), Amman, Jordan

[*]*Corresponding author:* arsyad@unhas.ac.id

Abstract

The integration of cattle production with oil palm plantations is increasingly promoted in Indonesia to enhance rural economies and support community livelihoods. Achieving long-term sustainability of this system requires a clear understanding of the institutional determinants that influence the implementation across social, economic, and ecological dimensions. Therefore, this study aims to examine the institutional determinants by identifying 5 key stakeholder groups in the cattle-oil palm sectors. The location was in Tanah Bumbu Regency, South Kalimantan, which was purposively selected for cattle-oil palm integration. Primary data were collected through field observations, structured questionnaires, and in-depth interviews with 15 purposively selected experts and were triangulated using secondary reports. Interpretive structural modeling (ISM) combined with MICMAC analysis was applied to identify, structure, and classify institutional constraints. The results showed a total of 13 institutional constraints, most of which were located in the linkage and dependent quadrants, indicating high interdependence and systemic vulnerability. Major constraints included inadequate coordination, weak leadership, limited institutional capacity, as well as insufficient regulatory and financial support. ISM generated 8 hierarchical constraint levels and 5 strategic program levels, regulation, financing, interagency collaboration, extension services, and waste processing technologies emerging as key drivers of system improvement. These results underscore the need for integrated institutional strengthening to enhance SISKA performance and sustainability. As the first to apply a combined MICMAC-ISM framework to cattle-oil palm integration, this study offers a novel institutional model to facilitate evidence-based policy design and strategic program planning.

Keywords: agricultural sustainability; cattle-oil palm integration; Interpretive Structural Modeling (ISM); policy intervention; silvopastoral system

Cite this as: Raisa, D. M., Sirajuddin, S. N., Syamsu, J. A., Arsyad, M., Rahim, L., Munizu, M., Jamil, M. H., Bahrun, A. H., Al-Tawaha, A. R. M., Nohong, B,, & Nurlaelah, S. (2026). Beef Self-Sufficiency and Oil Palm Sustainability: Developing a Cattle-Oil Palm Integration System in Indonesia. *Caraka Tani: Journal of Sustainable Agriculture*, *41*(1), 66-92. doi: http://dx.doi.org/10.20961/carakatani.v41i1.100400

[*] *Received for publication March 11, 2025*
Accepted after corrections December 16, 2025

INTRODUCTION

The rapid expansion of oil palm sector in Indonesia has significantly transformed rural economies by increasing farmer income, generating employment, and strengthening regional development, particularly in regions where smallholder plantations dominate the production landscapes (Dharmawan et al., 2020; Supriatna et al., 2024). Integrated crop-livestock system, specifically the cattle-oil palm integration system (SISKA), has been widely promoted because livestock grazing can reduce weeding costs, recycle nutrients, improve soil quality, and enhance system resilience (Umar et al., 2023; Álvarez et al., 2024). When implemented, this system supports Indonesia’s broader goals of achieving beef self-sufficiency and ensuring sustainable oil palm production. Despite these potential benefits, the implementation of integrated system across Indonesia remains inconsistent and constrained by institutional, technical, and socio-economic challenges.

Many smallholders still lack managerial capacity, access to capital, and adequate extension services needed to adopt sustainable integration practices (Bremer et al., 2022a; Firmansya et al., 2022). Weak institutional coordination, overlapping authority, limited cross-sector collaboration, and policy fragmentation further reduce the efficiency of multistakeholder engagement. Moreover, uneven technology adoption and limited private-sector participation also undermine system performance and restrict the scaling of integrated systems at the regional and national levels (Kassam et al., 2019; Brown et al., 2021; Ogahara et al., 2022). Given these persistent constraints, the success of cattle-oil palm integration depends not only on technical feasibility but also, crucially, on effective institutional arrangements, cohesive policies, and coordinated stakeholder actions, factors that remain underdeveloped in current practice.

The integrated cattle-oil palm system has shown promising outcomes in Kalimantan, due to cultural compatibility, strong community-based cooperatives, and the innovative use of by-products as feed. Furthermore, community-oriented agroecology models have proven more adaptive and sustainable than hierarchical plantation-based approaches, underscoring the importance of local participation and shared governance. Sustained government support, such as livestock subsidies in plantation areas, stricter land-use zoning, and improved animal health services, is crucial for maintaining system resilience and enabling gradual upscaling.

This collaborative policy environment allows farmers to adopt more sustainable practices without compromising environmental integrity. The approach is consistent with previous studies that emphasize the importance of strong institutional frameworks, adaptive technologies, and coordinated stakeholder management in advancing sustainable agricultural systems (Udayana, 2010; Lee et al., 2014; Raharja et al., 2020). Moreover, integrating cattle into oil palm landscapes directly contributes to several Sustainable Development Goals (SDGs), including poverty reduction, food security, responsible production, and climate action (Azhar et al., 2021), reinforcing SISKA’s potential as both an economic and environmental strategy for long-term rural development.

Despite the growing interest in cattle-oil palm integration, a substantial knowledge gap remains regarding the institutional dimension that shapes the sustainability and scalability of the system. Previous studies have predominantly focused on technical aspects of grazing management (Umar et al., 2023), nutrient cycling and waste utilization (Devendra, 2011), socio-economic benefits at farm level (Cramb and Sujang, 2013; Kabir et al., 2020), and farmer adoption behaviour (Yuhendra et al., 2022). However, very few have systematically examined how institutional interactions, leadership dynamics, policy coherence, and stakeholder roles jointly affect the performance of integration system.

Existing studies tend to analyze environmental or technical outcomes without explicitly identifying institutional restrictions or mapping influence dependence relationships among key actors. Consequently, policy recommendations are often broad and lack clear operational priorities on which institutional challenges should be addressed first to achieve systemic improvement. To date, no study has applied interpretive structural modelling (ISM) combined with MICMAC analysis to develop a hierarchical, empirically grounded framework that explains how institutional challenges interact, and the most strategic programs for strengthening cattle-oil palm integration in Indonesia. This absence of structured institutional analysis represents a critical study gap that needs to be addressed to support evidence-based policy design.

Institutional studies on oil palm sector emphasize limited participation and effectiveness of key agencies, partly due to weak human resources and the absence of strategic program. However, most of these studies largely stop at diagnosing constraints rather than translating into a coherent reform agenda (Rosada et al., 2025). At the same time, investigations on sustainability pressures show how Indonesia and Malaysia have responded to deforestation and emission concerns through certification schemes and other institutional frameworks (Marks et al., 2017). However, there is limited insight into how these frameworks concretely interact with and support SISKA in the field.

Studies on cattle–oil palm integration demonstrate multiple potential benefits for livelihoods, biodiversity, weed control, and food security (Azhar et al., 2021). These studies also acknowledge the importance of institutional collaboration among government agencies and farmer organizations (Raisa et al., 2024), but tend to treat institutional factors in a descriptive or fragmented manner. Previous work on strategic program development shows that ISM and MICMAC can be used to construct hierarchical policy structures (Raisa et al., 2024). Strong institutional policy frameworks are needed to strengthen capacity and coordination (Hospes et al., 2017; Rachman et al., 2024). These approaches have not been systematically applied to the specific case of cattle-oil palm integration in Indonesia.

Finally, broader analyses point to persistent operational challenges such as the lack of standardized processing for cattle feed, risks of cattle damaging plantations, and uneven enforcement of certification and policy instruments across regions (Silalahi et al., 2019; Judijanto, 2025). However, it does not offer a clear institutional roadmap that links these field-level issues to prioritized strategic programs. Collectively, the literature has not provided an integrated, empirically grounded institutional framework that hierarchically maps key constraints. Such a framework is needed to connect and align them with concrete strategic programs, thereby guiding stakeholders in designing coordinated interventions for sustainable cattle-oil palm integration systems. Therefore, this study aims to examine the institutional determinants by identifying key stakeholder groups in cattle-oil palm sectors.

MATERIALS AND METHOD

Time and location

This study was conducted from July 2023 to December 2024 in Tanah Bumbu Regency, South Kalimantan Province, Indonesia. Based on the criteria in Figure 1, the selection of this location was based on several strategic considerations. Tanah Bumbu is an area with extensive oil palm development and an established cattle population, making it highly suitable for studying the integrated cattle and oil palm system. The regency contains a diverse structure of oil palm ownership, smallholder plantations, large government-owned estates, privately owned estates, and independent plantations. This allows for a comprehensive assessment of different management practices and integration models.

Tanah Bumbu is also recognized as a regional hub for the development of SISKA, where cattle-oil palm can improve land-use efficiency, reduce weeding costs, and enhance soil fertility. This makes the area particularly relevant for studies exploring productivity, sustainability, and socioeconomic impacts of integration. Climatically, Tanah Bumbu has a tropical rainforest climate, with daily temperatures ranging from 24 to 32 °C (75 to 90 °F) and high annual rainfall. The combination of suitable climate, diverse plantation ownership, and active integration practices reinforces the area's relevance as a representative and strategic site for cattle and oil palm integration studies.

Data collection

Purposive sampling was used to identify Tanah Bumbu as a prospective prototype for SISKA development. The designation was based on several considerations: 1) the importance of the area as a center for SISKA, 2) support from various stakeholders (public, voluntary, and private sectors) to increase cattle population and establish sustainable oil palm plantations, particularly through SISKA system. 3) The need to understand group dynamics in fostering the development of SISKA. And 4) implementation of South Kalimantan super priority program SISKA KUINTIP as stipulated in South Kalimantan Governor Regulation No. 53 of 2021. This study was conducted in Tanah Bumbu Regency, South Kalimantan Province, which plays a key role in implementing the SISKA system.

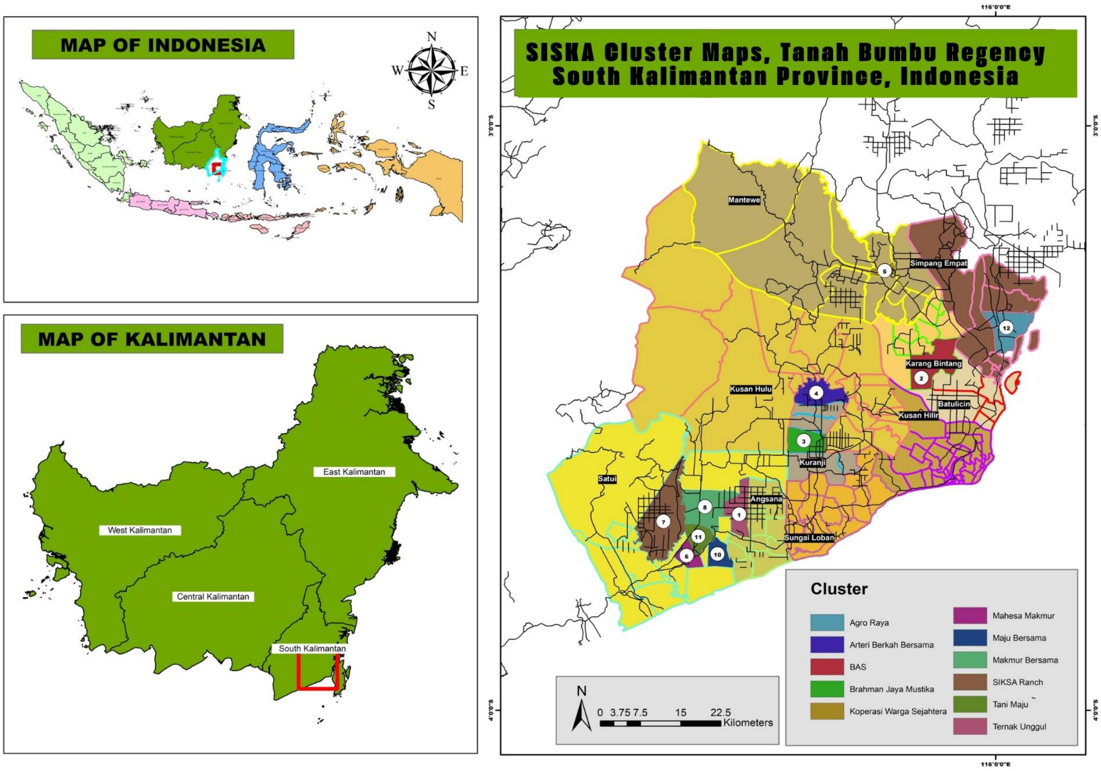

Figure 1. Study map

Data analysis

A descriptive qualitative study design was used to examine the complexity of SISKA. A qualitative approach was selected because the phenomenon comprised multi-actor interactions, institutional arrangements, and policy dynamics that require contextual interpretation rather than numerical measurement. Qualitative inquiry enables the capture of expert insights, institutional realities, and underlying relationships that shape system performance (Creswell and David, 2018). In this study, SISKA served as the bounded case, providing a structured context for exploring how leadership, coordination, resource allocation, and community participation influence system execution. Data were collected using semi-structured questionnaires administered during expert interviews. This instrument supports systematic but flexible inquiry, allowing experts to elaborate on experiences, operational challenges, and strategic considerations relevant to integration efforts (Rade et al., 2017). The stages of data collection are shown in Figure 2.

Informant selection

The informants were experts in the field of SISKA development, determined using purposive sampling. The inclusion criteria include experts who had experience, reputation, position, and authority in the field under study, were willing to conduct in-depth interviews, and had influence and interest in the development of SISKA. Field and industrial observations, as well as professionally evaluated in-depth interviews, were used to examine complex, problematic, and unstructured topics. This study intentionally allocated specialists based on expertise in the experimental domain. Two criteria were established to select qualified specialists: (1) experience in developing SISKA and (2) a comprehensive understanding of the creation of SISKA. To participate in the experimental panel, invitations were extended to the central government, local government, communities, academics, and financial institutions. The recommended number of experts in ISM field should be limited, with a minimum of two members. This study comprised 15 experts who functioned as purposive sample. The attributes and specifics of these experts are listed in Table 1.

Identification of elements and sub-elements

This study examined a restricted selection of investigations that explicitly addressed the challenges and methodologies associated with establishing SISKA. Therefore, this study aims to determine and develop a framework for advancing a system that integrates cattle and oil palm farming using the ISM approach. Decision-makers often use this method to establish

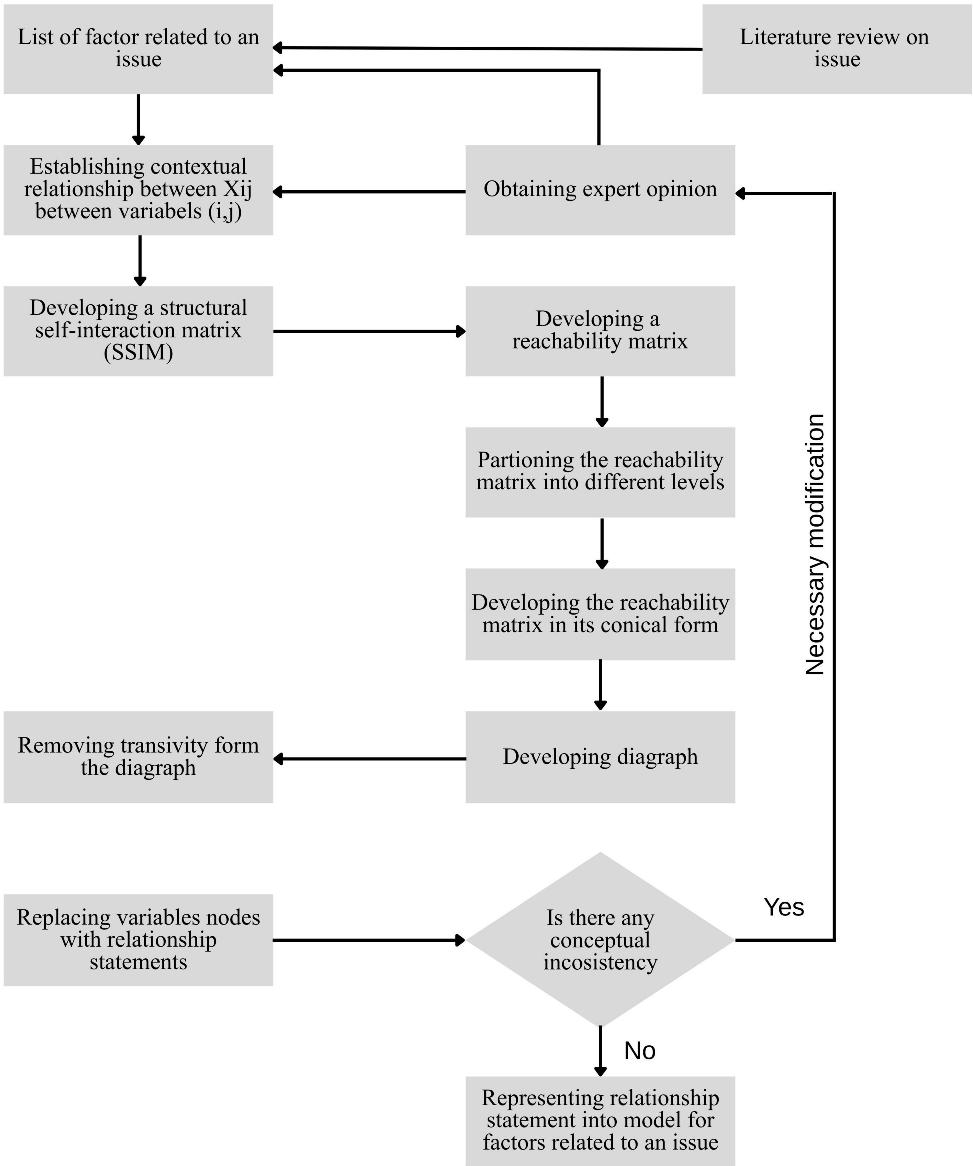

Figure 2. ISM flow diagram

connections between identified challenges and initiatives that show significant momentum and demand paramount focus. This study significantly relies on the perspectives of several experts invited to the panel. Table 2 shows the 13 challenges and 14 strategies.

To enhance SISKA, a detailed analysis to discover viable alternatives is essential. The enhancement can be observed in strategic initiatives designed to streamline integration and implementation. The data collected has considerable potential for program assessment and the development of future initiatives. Moreover, this study will identify the difficulties in adopting SISKA as well as provide an ideal strategic approach for integrating oil palm into both small- and large-scale plantations.

Construction of structural self-interaction matrix (SSIM)

This study applied ISM method (Figure 2) to systematically examine the complex and interdependent factors influencing the development of SISKA. As a methodological framework originally designed for analyzing multifaceted socioeconomic systems, ISM enables the decomposition of complexity by structuring expert knowledge, experiential insights, and analytical logic into a coherent multilevel model (Attri et al., 2013). In this study, key factors were initially identified through a rigorous literature review and subsequently validated by subject-matter experts, whose judgments constituted the primary qualitative data. The contextual relationships among

Table 1. The expert profiles

Expert	Position
Central government	1. Medical Veterinary Expert at Veterinary Center Banjarbaru
Local government	2. Medical Veterinary 3. Head of Livestock and Animal Health Division, Department of Food Security and Agriculture (DKPP) of Tanah Bumbu Regency 4. Head of Plantation Division, Department of Food Security and Agriculture (DKPP) of Tanah Bumbu Regency 5. Secretary of the South Kalimantan Plantation and Livestock Service 6. Head of the Production and Feed Section of the South Kalimantan Plantation and Livestock Service 7. Agricultural Extension of Tanah Bumbu Regency
Community	8. Association of Indonesian Oil Palm Entrepreneurs (GAPKI) of South Kalimantan 9. Association of Actors and Observers of Cattle-Oil Palm Integration System (GAPENSISKA) 10. Cluster Tani Maju
Academics	11. Researcher and Professor at Universitas Lambung Mangkurat 12. Researcher and Professor at Universitas Islam Kalimantan Muhammad Arsyad Al Banjari Banjarmasin
Private	13. Staff of UMK Division, Bank of South Kalimantan 14. Director of PT. Simbiosis Karya Agroindustri

variables were elicited using VAXO notation through structured questionnaires administered to specialists, forming the basis for constructing SSIM (Ali et al., 2023). According to Attri et al. (2013) and Arsyad et al. (2020), SSIM can be constructed using the results of the questionnaire. This matrix represents respondents' answers, expressed in 4 symbols representing the relationship between the 2 elements being studied. The 4 symbols are:

V = When sub-element A has a contextual relationship with sub-element B, not vice versa.

A = When sub-element B has a contextual relationship with sub-element A, not vice versa.

X = When sub-element A and sub-element B have a contextual relationship.

O = When sub-element A and sub-element B have no contextual relationship.

Development and validation of the reachability matrix (RM)

SSIM was further transformed into a binary RM, subjected to transitivity checks, and partitioned into hierarchical levels, leading to the development of a conical matrix and a directed graph that captured the directional dependencies among factors. Redundancies were removed through transitivity reduction, and iterative expert feedback ensured conceptual consistency and structural validity. All computational procedures, including matrix conversion, logical verification, and hierarchy derivation, were executed using Microsoft Excel and dedicated ISM software. The final outputs, comprising hierarchical level partitions and ISM digraphs, were visually represented using diagramming tools. The resulting ISM model offers a strong structural interpretation of the system, clarifying critical leverage points and relational pathways that are essential for informing strategic decision-making in cattle and oil palm integration framework. Subsequently, the initial matrix was modified to show all direct and indirect relationships, and produce the final RM, namely, when Eij = 1 and Ejk = 1, then Eik = 1. Eij is the contextual relationship from element Ei to element Ej.

MICMAC analysis

The clustering factors develop a Canonical Matrix at the levels reached across all rows and columns in the final RM. The resulting matrix has most of the upper triangular elements as 0 and the lower triangular elements as 1. This matrix was then used to construct a digraph, which is a graphical representation of elements, directed relationships, and hierarchical levels. The initial digraph was prepared based on the Canonical Matrix for the problem under consideration (Rade et al., 2017). The final matrix was processed to obtain Driver Power and Dependence (DP-D) values, resulting in a directed graph, a graph of directly related elements classified by hierarchical level, into 4 sectors:

Table 2. Identification of challenges and strategies sub-elements for enhancing beef self-sufficiency and oil palm sustainability

Challenges	Remarks
B1	Limited human resources of institutions
B2	Parties or figures who prioritize personal interest in program development
B3	Lack of managerial capacity for institutional management
B4	No major institutions are working as coordinators
B5	Budget constraints
B6	Lack of leadership dynamics
B7	Lack of integration and synchronization of work programs
B8	Lack of understanding of the role of each main task and functions of the institution
B9	Attitude of cluster members who are difficult to train
B10	Institutional hierarchy
B11	Limited policy, coaching, and funding support
B12	Limited clients and coalitions to support program implementation
B13	Lack of commitment to the implementation of goals
Strategy	**Remarks**
C1	Provision of access to capital
C2	Awareness of independent farmers to join a group or institution
C3	Counseling (upstream-downstream)
C4	Industry support to partner with farmer-breeder institutions
C5	Support (regulations/policies, funding, and guidance) of central and local government
C6	Effectiveness of interagency coordination
C7	Improving the abilities and skills of cluster members in GAP and sustainable development
C8	Increased independent bargaining
C9	SISKA human resource improvement
C10	Extensification of plantation land
C11	Provision of processing technology or tools for the development of SISKA
C12	Formation of a special SISKA development team
C13	Availability, smooth access, and financing support from financial institutions
C14	Production facilities assistance program

(i) Weak driver-weak dependent variables (Autonomous): Sub-elements in this sector are generally unrelated to the system or may have slight relationship. A sub-element is assigned to sector (i) when DP $\leq$ 0.5 and D $\leq$ 0.5;
(ii) Weak driver-strongly dependent variables (Dependent): The sub-element in a position is not independent but depends on the sub-element above it. A sub-element is assigned to sector (ii) when DP $\leq$ 0.5 and D > 0.5;
(iii) Strong driver-strongly dependent variables (Linkage): Sub-elements in this sector need to be studied due to unstable relationships. A sub-element is assigned to sector (iii) when DP > 0.5 and D > 0.5;
(iv) Strong driver-weak dependent variables (Independent): Sub-elements in this sector are independent variables that significantly influence other sub-elements. A sub-element enters sector (iv) when DP value > 0.5 and D $\leq$0.5.

ISM hierarchical model development

To create level partitions, all elements must be classified into different levels of ISM structure. Based on this, 2 sets are associated with each element in the system:
(i) Reachability set (R), the set of elements that can be reached by element Ej;
(ii) Antecedent set (A), the set of elements from which element Ei can be reached.

Reachability and antecedent for each factor are obtained from the final matrix. In general, reachability set consists of the variable and other contributing factors. Antecedent set consists of the variable and other factors that contribute to reachability. The intersection of these sets is derived for all variables. After identifying the top-level element, it was removed from the remaining variables. This iteration continued until the levels for each variable were obtained using ISM hierarchical model development.

RESULTS AND DISCUSSION

Demographic

Tanah Bumbu Regency is a region in South Kalimantan Province with unique demographic characteristics influenced by geographic, economic, and sociocultural factors. According to recent data, the regency population continues to grow in line with the development of the plantation, mining, and trade sectors, which serve as the backbone of the local economy. The population of Tanah Bumbu Regency is estimated at 343,741 people, with a relatively low population density due to the relatively large area. The majority is in Kusan Hilir (34,498), Kusan Tengah (15,754), Sungai Loban (26,055), Satui (57,067), Angsana (23,941), Kusan Hulu (12,176), Kuranji (10,662), Teluk Kepayang (9,616), Batulicin (22,944), Karang Bintang (21,140), Simpang Empat (84,925), Mantewe (25,413), and Tanah Bumbu (343,741). The Tanah Bumbu population is predominantly of the productive age group (15 to 64), reflecting the significant human resource potential for development. Meanwhile, the younger generation under 15 years old is also quite significant, reflecting a high birth rate. The gender distribution is balanced between males and females.

Plantation conditions in Tanah Bumbu Regency, South Kalimantan Province, are an area with promising agricultural and plantation potential. It is one of the food barns and producers of major plantation commodities in Kalimantan. Rubber crops accounted for 23,014 thousand tons, coconuts 1,327 thousand tons, oil palm 624,865 thousand tons, coffee 4,000 tons, and cocoa 4,000 tons. The region’s fertile soil and favorable climate contribute to the successful cultivation of these crops. The local farmers are increasingly adopting sustainable practices to enhance productivity while preserving the environment.

Institutional constraints analysis

This study provides a comprehensive structural analysis of the institutional, social, and managerial constraints influencing the development of SISKA in Tanah Bumbu Regency. In contrast to earlier assumptions that technical limitations and environmental factors form the main obstacles, ISM-MICMAC analysis identifies institutional and governance-related constraints, including lack of institutions coordinating, limited policy support, and weak managerial capacity, as the most dominant and fundamental drivers of system failure.

The results counter the conclusions of earlier studies that placed greater emphasis on production-level constraints. For instance, Devendra (2012) and Baliarti et al. (2020) attributed performance gaps primarily to insufficient feed resources or limited adoption of improved technologies. However, the hierarchical structure uncovered in this study shows that the technical issues are downstream consequences of deeper institutional dysfunctions. This distinguishes the present study from much of the earlier literature by providing a structural, rather than descriptive, explanation for persistent failures in integration initiatives.

A recent study describes cattle-oil palm integration as a sustainable intensification model with environmental benefits, particularly in terms of nutrient cycling and weed control (Álvarez et al., 2024). Meanwhile, this study emphasized that environmental advantages cannot be fully achieved without strengthening institutional coordination and ensuring consistent program implementation. This provides an important corrective to the sustainability-focused literature, which often underestimates the institutional and behavioral complexities shaping the success of the integration system. Studies by Bremer et al. (2022b) and Ogahara et al. (2022) emphasized smallholder social networks, local leadership, and cooperative capacity as key determinants of integration success.

Based on these results, RM was developed using SSIM (Appendix 1 and Appendix 2). The matrix was refined to obtain a closed phase consistent with the transitivity requirement, which requires the completeness of the entire circular causal chain (causal loop). In this case, X must affect Z when Y and Z are both affected by X. More judgments were made to determine the level of compliance from 0-1 valued cells to the transitivity requirement (Appendix 2). When this level is not observed, changes must be made to ensure proper adherence to the transitivity criteria. The final RM (Appendix 3) was also improved following the checks in Appendix 4.

The Canonical Matrix results in Appendix 4 classify the institutions into 4 quadrants, as shown in Figure 3, which presents MICMAC constraints in the development of SISKA. Figure 3 also shows the distribution of issues across 4 categories. Behavioral constraints, such as actors prioritizing personal interests (B2) and cluster members who are difficult to train (B9), are structurally dependent elements, relying heavily on higher-level institutional and policy drivers.

This clarifies why past programs often failed even when strong farmer groups existed. The system lacks cohesive command, synchronized program implementation, and effective multi-stakeholder governance. Earlier studies (Jelsma et al., 2017; Ogahara et al., 2022) have identified weak regulatory frameworks and financial mechanism failures as barriers. This study adds precision by positioning budget constraints (B5) and limited coalitions (B12) at mid-levels of ISM hierarchy. Based on the results, financial barriers are not root causes but emergent effects of deeper leadership and coordination deficiencies, an important differentiation previously absent from the literature.

ISM analysis identified 8 hierarchical levels of constraints, demonstrating that the institutional landscape governing cattle-oil palm integration is deeply layered and structurally interdependent. Key institutional constraints, including lack of managerial capacity (B3), absence of a coordinating agency (B4), and limited understanding of institutional roles (B8), were positioned at higher form levels of the hierarchy, confirming the role as primary drivers of systemic inefficiency. Mid-level constraints comprised limited policy support (B11), program fragmentation (B7), and budget inefficiencies (B5). These elements form the "functional gap layer," where operational failures stem from incomplete institutional coherence. Technical and behavioral constraints were in the lower levels, meaning the resolution depends on addressing structural governance issues first. This hierarchical perspective strengthens theoretical understanding by demonstrating that successful cattle-oil palm integration requires a top-down sequence of reforms, institutional realignment to technical improvements.

MICMAC analysis provides a deeper understanding of how different constraints interact in SISKA and illustrates the tightly coupled nature of the institutional environment. Interestingly, no constraints fell in Quadrant I (autonomous elements), indicating that the system lacks peripheral or low-influence factors. The absence suggests a highly interdependent structure in which every constraint exerts significant influence on system performance. This configuration contrasts sharply with many ISM applications in agricultural development, where autonomous elements commonly arise and allow policymakers to prioritize only a subset of issues. However, in the case of SISKA, the lack of autonomous factors underscores that all constraints require policy attention, reaffirming the system's structural sensitivity and the need for holistic intervention strategies.

Quadrant II (dependent elements) comprises constraints significantly shaped by decisions and actions at higher institutional levels. These include self-interested actors (B2), cluster members who are difficult to train (B9), and rigid institutional hierarchies (B10). The dependent positioning shows that behavioral and social challenges cannot be resolved solely through

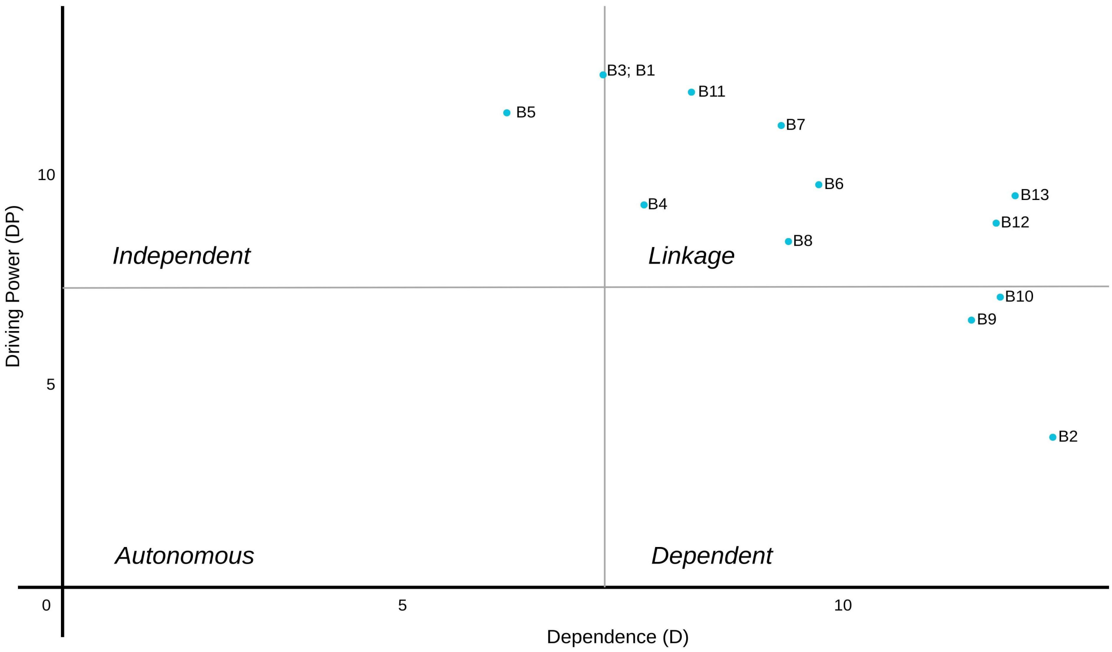

Figure 3. MICMAC challenges in the development of SISKA

farmer-level training or capacity-building efforts. The behaviors reflect deeper institutional and governance shortcomings. This is consistent with recent literature indicating that smallholder decision-making is deeply embedded in broader organizational structures, and individual behavior may not change without systemic institutional reform. Therefore, interventions targeting the constraints must be preceded by adjustments in institutional authority, clarity of roles, and accountability mechanisms.

The most dynamic and unstable elements were in Quadrant III, the linkage quadrant, which contains the majority of constraints, including managerial limitations (B3), poor synchronization of institutional work programs (B7), and insufficient policy, coaching, and funding support (B11). Elements in this quadrant exert a strong influence on other factors while simultaneously being heavily influenced in return, creating a feedback-rich environment highly sensitive to policy shifts. Intervening in linkage elements without addressing structural root causes can amplify contradictions, create policy friction, and destabilize the system. This result is supported by studies advocating against piecemeal policy reforms in complex agricultural systems, emphasizing that interventions in highly interdependent environments must be carefully sequenced to avoid counterproductive outcomes.

Quadrant IV (independent elements) includes constraints with high driving power and low dependency, remarkably limited institutional human resources (B1), and budget constraints (B5). These factors function as strategic leverage points, exerting substantial influence over the system while being relatively less affected by other constraints. The placement that improvements in human resource capacity and financial allocation could generate positive systemic effects across institutional, managerial, and behavioral dimensions. Interestingly, the result challenges previous literature that frames financial limitations as downstream operational problems. Conversely, this study positions financial limitations as structural drivers capable of reshaping the overall effectiveness of integration strategies.

The insights contribute meaningfully to advancing theoretical and practical understanding of SISKA. First, the study shifts attention from technical issues such as feed availability or technology adoption that have dominated earlier analyses, and instead identifies structural institutional failures to be the primary determinants of system performance. Second, ISM-MICMAC approach offers a validated causal model explaining why integration initiatives have produced inconsistent outcomes over the past two decades. Interventions often targeted dependent or linkage elements without first addressing structural drivers. Third, the repositioning of financial and HR constraints as high-influence structural variables contradicts earlier interpretations that treated the variables as operational challenges, demonstrating the need to redesign SISKA governance and resource allocation frameworks.

Overall, this study demonstrates that partial, sector-specific, or technically oriented interventions are insufficient in a tightly interconnected institutional ecosystem. The results underscore the importance of a systemic policy roadmap that advocates strengthening institutional authority, formalizing coordination mechanisms, aligning policy instruments with financial support, and then deploying technical and operational programs. By articulating the relationships, this study contributes an evidence-based framework that supports more coherent, scalable, and sustainable governance of SISKA.

Program strategy analysis

Based on the results, RM was developed using SSIM (Appendix 5 and 6), then the matrix was refined to obtain a closed phase consistent with the transitivity requirement, which demands the completeness of the entire circular causal chain (causal loop). In this case, X needs to affect Z when Y and Z are both affected by X. More judgments are made to determine the level of compliance of 0-1 valued cells to the transitivity requirement (Appendix 6). When this level is not observed, changes must be made to ensure proper adherence to the transitivity criteria. The final RM (Appendix 7) was also improved based on the checks in Appendix 7. The Canonical Matrix results are shown in Appendix 8, which presents the institutions broken down into 4 quadrants. Figure 5 illustrates the number of issues classified into 4 categories.

ISM-MICMAC analysis identified 14 strategic programs (C1 to C14) for the development of SISKA in Tanah Bumbu. These programs form a highly interconnected structure in which most elements show both strong driving and strong dependence relations. In MICMAC classification, the majority of the programs (C1 to C9, C11 to C14) are located in the linkage quadrant, simultaneously acting as drivers and being sensitive to changes in other elements. Only one program, “Plantation Land Extensification” (C10), appeared in the dependent quadrant, characterized by low driving power and high dependence, while no program fell into the independent or autonomous quadrants. This configuration suggests SISKA development in the study area was dominated by complex feedbacks rather than isolated levers, which is consistent with previous applications of ISM-MICMAC in agricultural and rural development contexts (Singh et al., 2023).

The hierarchical ISM model further organized the 14 programs shown in Figure 6 into 5 levels, reflecting an implicit sequence for intervention. At the higher levels of the hierarchy, farmer-facing and operational programs dominate, including improving or facilitating access to capital (C1), strengthening awareness and membership in farmer or plantation groups (C2), enhancing upstream and downstream extension and advisory services (C3), and securing industry or company support for SISKA (C4). Due to the position, these programs are interpreted as levers that directly shape farm-level decision-making and the daily functioning of the integration system. The prominence at the top of the hierarchy indicates that SISKA performance is immediately contingent on the quality of financial access, farmer organization, extension, and private sector engagement.

At the intermediate levels (Levels 2 and 3), ISM model shows policy, technological, institutional, and capacity-building programs as structural enablers. Level 2 was composed of government regulations, funding schemes, and development initiatives, providing the formal governance framework for SISKA (C5), together with those along with supporting technology for processing cattle and oil palm by-products (C11), the establishment of a specialized SISKA development team or coordination unit (C12), and financial support from banks and other financial institutions (C13). These elements are interpreted as the “backbone” that stabilizes incentives, reduces uncertainty, and anchors SISKA in broader policy and financial architectures.

Level 3 comprises programs designed to translate this enabling environment into concrete services, including strengthening inter-institutional collaboration (C6), enhancing cluster members’ technical and managerial capabilities (C7), investing in human resource development for SISKA (C9), and providing production facilities and technical assistance (C14). Collectively, these programs bridge high-level policy and finance with operational changes on the ground, and the intermediate location indicates the benefit of mediating the influence of structural factors on farmer-level outcomes.

Level 4 was represented by a single program, namely, improving independent bargaining power (C8). This program captures the rise of stronger market positions for farmers and cooperatives, following improvement in access to information, infrastructure, institutions, and finance. The position immediately above the lowest level suggests that enhanced bargaining power is not an entry point for SISKA development but a consequence of upstream investments in governance, capacity, and service delivery.

Finally, Level 5 consists solely of the plantation land extensification program (C10), which appears as a long-term, dependent outcome. The location at the bottom of the hierarchy and in the dependent quadrant indicates that any expansion of the land area used for SISKA is conditioned by the previous effectiveness of the institutional, financial, technological, and human-resource programs at higher levels, rather than acting as a primary driver of system transformation. This result contrasts with narratives that place land expansion at the center of integration efforts and rather frames extensification as contingent on broader system strengthening.

Institutional implications

Institutions play a crucial role in driving the success of multistakeholder integration in this system. These roles cover various aspects, including resource management, technology provision, collaboration facilitation, and policy setting. However, the institutions face many challenges in optimally performing the roles. The challenges include a lack of coordination between government, private, and community institutions, limited competent human resources, and overlapping policies that hinder multi-stakeholder synergy. Therefore, enhancing traditional approaches to technology delivery is essential by incorporating farmer extension study interactions, accelerating technology dissemination, increasing technology adoption, and enhancing the impact of SISKA.

Significant constraints to the successful use of feed resources include the failure to adopt a holistic perspective on the livestock system and insufficient linkages to practical agricultural contexts. The strategy emphasizes optimizing feed resource efficiency, intensive use of agricultural residues, increased integration of ruminant oil palm systems, and the use of oil palm by-products. This strategy underscores the need for rapid and widespread application, adoption, and implementation. It requires the application of advanced technology and rigorous implementation of systematic methodologies. Development of strategies to adapt to and mitigate the impacts of climate change on feed resources, increased collaboration among studies, extension services, and farmers, establishment of a year-round feeding system, and efforts to achieve sustainability in integrated farming systems.

The association model is based on the results showing that the current function of associations is limited to organizing programs and activities for member development, training, and capacity building. This model increases the efficiency of independent farmers and is important for addressing a range of fundamental issues, including resolving disputes about the legitimacy of land, agricultural products, and certification. Plantation industry participants are expected to act as guarantors, fostering a sense of security among oil palm refiners in the downstream sector. Furthermore, this study recommends the integration of all proposed institutional models into a cohesive primary model.

The analysis shows that the optimal institutional framework for advancing beef self-sufficiency and oil palm sustainability initiatives is an integrated model, with cooperatives serving as the main institution to assist farmers and cattle ranchers in the study area. Farmer needs and awareness drive the formation of the cooperatives, which can operate effectively. Cooperative members highly value the individuals who set the criteria, as adherence to these standards is mandatory for all members. However, the institutional improvement of local clusters requires support from several organizations, considering the roles and responsibilities of each member. This underscores the need to prioritize leadership development in the implementation of SISKA. The ability to improve a particular governance system is influenced by various environmental, market, and social elements across the sector (Shahzad et al., 2024).

The effectiveness of the development process depends on collaboration between the parties concerned. The association can enhance collaboration among members to share valuable knowledge and skills in developing and managing SISKA. This may require the allocation of shared resources, including processing facilities, distribution systems, and technology upgrades. In addition, it can facilitate the optimization of certification procedures for integrated products, thereby increasing market competitiveness and profitability. The association also has the capacity to effectively recognize obstacles that may arise during the implementation of SISKA and ensure compliance with laws on sustainable practices. Effectively implementing SISKA requires the participation of many stakeholders, including smallholder groups (Abid et al., 2017).

Farmers use decentralized and informal associations and networks to obtain various service benefits. These associations largely consist of close-knit social networks and agricultural cooperative partners that operate on the principles of trust and reciprocity, providing mutual assistance when needed (Schut et al., 2015). Innovation competence refers to the ability of individuals and organizations to leverage skills, expertise, and experience to consistently identify as well as prioritize innovation challenges and opportunities in a dynamic environment.

Engaging multiple stakeholders at the regional or local level has a more significant impact. Strategic planning is needed to optimize the integration system, considering the diverse scale of oil palm plantations and the need for strong partnerships among stakeholders (Raisa et al., 2024). An integration system can contribute to environmental sustainability by reducing herbicide use, increasing biodiversity, and improving soil quality. However, widespread adoption of these systems is limited, suggesting the need for more policies that support sustainable practices (Umar et al., 2023; Álvarez et al., 2024). Although integrating the oil palm system offers promising benefits, challenges such as institutional coordination, environmental sustainability, and resource efficiency must be addressed. The success of the system depends on strategic planning, effective stakeholder collaboration, and practical implementation (Firmansya et al., 2022).

Figure 4 shows that the results present 8 levels, each consisting of 13 sub-elements, signifying the implementation of SISKA. Certain parties or individuals prioritize personal interests in the development of the program, making it difficult to foster the attitudes of cluster members. This suggests that certain sub-elements pose significant barriers to the implementation of SISKA. According to Yuhendra et al. (2022), farmers' choice to integrate oil palm cattle is significantly influenced by various aspects, such as the length of involvement of cluster members in oil palm cultivation, extension services provided, income earned from oil palm, and household dependency ratio. In contrast, formal education and activeness in farmer groups or cooperatives generally deterred smallholders from embracing cattle and oil palm integration. More specifically, farmers with advanced formal education found integration less attractive, and participation in cooperatives did not increase propensity to adopt this approach.

Strategic implications

The dominance of linkage-type programs in MICMAC results indicates that SISKA development in Tanah Bumbu is characterized by mutual interdependencies rather than isolated "magic bullet" interventions. In the system, changes in one program, for example, adjustments in credit access, extension services, or regulatory support, may propagate through the network and alter the effectiveness of others. This result is consistent with the broader ISM–MICMAC literature, which demonstrates that in complex socio-technical systems, a significant number of elements often occupy linkage positions. Consequently, these systems require integrated, multifaceted policy responses rather than isolated, single-instrument interventions (Agrawal, 2019; Barati et al., 2019; Ahmad, 2024; Quttainah and Singh, 2024; Han et al., 2025). In practical terms, the presence of multiple linkage programs suggests SISKA interventions should be designed as coherent packages combining finance, extension, organization, and technology rather than independent projects that risk creating new bottlenecks elsewhere in the system.

The hierarchical ISM structure refines the results by clarifying the sequencing logic implied by MICMAC classification. Programs related to regulations, development funding, technology provision, and specialized coordination (C5, C11 to C13) form structural backbone that shapes incentives and capacities for SISKA implementation. Without a stable governance framework and dedicated institutional arrangements, improvements in credit access or farmer training may not be sustained. Similarly, capacity-building and service-delivery programs (C6, C7, C9, C14) ensure that farmers, extension agents, and private partners can translate formal rules and financial instruments into tangible changes in cattle and oil palm management. The growth of stronger bargaining power (C8) at Level 4 reflects a cumulative effect. Farmers can negotiate better terms only when previous investments have improved organizational strength, market information, and access to services. This layered pattern is in line with previous ISM-MICMAC studies that find institutional and governance factors to be deep drivers of performance, while market outcomes such as bargaining power or profitability tend to be more dependent (Singh et al., 2018; Inumula et al., 2020; Singh, 2020; Ahmadzai et al., 2021; Kumar et al., 2023). In this architecture,

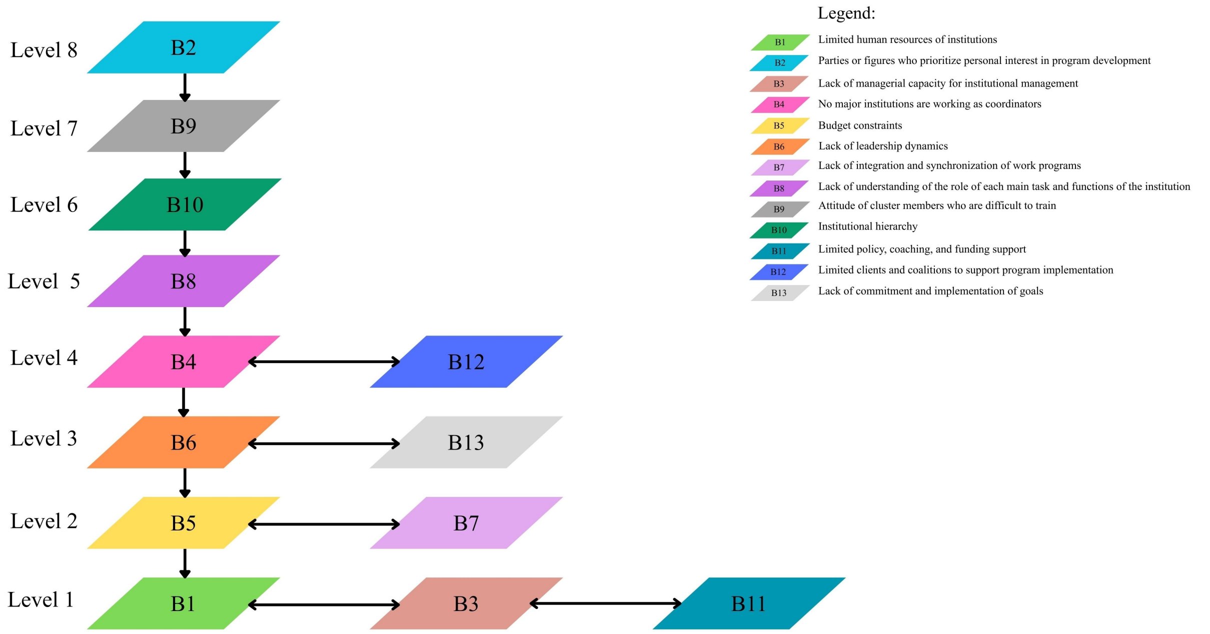

Figure 4. ISM hierarchical structure of constraints

the position of "Plantation Land Extensification" (C10) as a lowest-level, and dependent program has important conceptual and policy implications.

The implementation of cattle-oil palm integration system development requires the active participation of several stakeholders, including the government, academics, oil palm plantation companies (nucleus and plasma), cooperatives, and financial institutions. After one and a half decades of implementation, the results provided strategies to improve the cattle-oil palm integration system. This development is evident in the strategic programs designed to facilitate the implementation of integration. The data generated in this study proved to be very efficient for program evaluation and formulating future development strategies.

At the first level, extension programs, through an upstream-downstream approach, are essential for improving sustainable cattle-oil palm integration system. Integrated farming system of cattle and oil palm covering the upstream to downstream sectors plays an important role in increasing knowledge, fostering participation of cluster members, facilitating communication, and reducing conflicts between farmers and breeders. In addition, this extension approach has improved cattle rearing and oil palm waste processing skills. Providing key information to cluster members is essential to increasing progress and engagement in the integration of cattle and oil palm. This mainly relates to various aspects, including oil palm cultivation techniques, beef cattle rearing, integrating oil palm and cattle, managing farming operations, marketing products, ensuring environmental sustainability, and maintaining animal health.

The benefits align with several researchers (Vendramini and Moriel, 2018; Sihombing et al., 2020; Baharim et al., 2022; Rohaeni et al., 2025) who examined institutions that adopted the livestock-oil palm integration model by engaging in business diversification activities, such as the production of manure, liquid fertilizer, and biogas. The combination of beef cattle and oil palm can facilitate the development of a bio-industry centered on the production of solid organic fertilizer (from cattle dung) and liquid organic fertilizer (from cattle urine). The main objective is to increase income generation and optimize livestock waste use to support sustainable oil palm plantations. This will be achieved through mentoring and extension services. Solid and liquid organic fertilizers are marketed and distributed to group members and local farms.

Facilitating financial accessibility is a crucial factor in driving the progress of cattle-palm integration. This is due to the use of accessible resources and support systems, such as the credit guarantee program (KUR), capital assistance, production input assistance, and marketing assistance, which have the potential to improve the welfare of cluster members by strengthening income and economic well-being. Obstacles to development can be attributed to insufficient capital, a major hindrance that farmers face in obtaining high-quality inputs consistently (Cramb and Sujang, 2013; Soliman et al., 2016; Jelsma et al., 2017; Ogahara et al., 2022).

Strategic initiatives include establishing collaborative entities that combine oil palm cultivation and cattle rearing, often known as oil palm cattle integration. This practice requires the simultaneous operation of cattle breeding enterprises and oil palm fields. Farmers and planters can either become members of a farmer association, commonly called a "farmer group (Poknak)," or join a "plantation group (Kopbun)." Practical implementation of cattle-oil palm integration is achieved by participating in farmer or plantation groups, which allow optimal use of the empty space between the oil palm rows. Farmer plantation groups or cooperatives can rent or use dedicated land for rearing cattle.

The study by Sihombing et al. (2020) reported the prospective use of oil palm industry by-products derived from biomass, including fronds, leaves, palm kernel cake, and solids from waste, as a viable source of animal feed. Farmer groups or cooperatives use oil palm waste as a source of animal feed, including empty fruit bunches, palm fiber, and palm kernel cake. Small-scale and individual farmers can potentially benefit from using pre-existing resources and facilities, as well as establishing coordinated strategies for management and sales. According to Raharja et al. (2020), institutional variables in a group have a positive impact on plantation-related decision-making processes. Furthermore, the extent of this impact, through regulations or laws, studies, or improved access to capital, directly correlates with the opportunity to integrate oil palm and cattle. Supporting industries are important in integration programs for oil palm cattle development.

At the second level, there are strategic programs, including regulation, funding, and development of government initiatives, as well as the provision of technology for processing cattle or oil palm waste. In addition, the acquisition of financial support from financial institutions is also an important component in the development of SISKA (Ali et al., 2015). The watershed institutional study investigated the factors that contribute to less-than-optimal coordination functions between institutions. The results showed that the main factor behind this problem is the lack of strong commitment to cooperation among government officials at the local level and the absence of a regulatory framework (Plantation and Livestock Service of South Kalimantan, 2024). The strategic programs are considered very important and effective in facilitating the implementation of the cattle-oil palm integration system, thereby fostering the development.

Several legal documents support the implementation of this integration system program. These include Law No. 39/2014 on Plantations, Presidential Instruction (INPRES) No. 6/2019 on the National Action Plan for Sustainable Oil Palm Plantations 2019-2024, and Minister of Agriculture Regulation No. 105/Permentan/PD.300/8/2014 on the Integration of Oil Palm Plantation Business with Beef Cattle Farming Business. Another regulation is the South Kalimantan Provincial Regulation No. 2 of 2013 on Sustainable Plantation Development, and South Kalimantan Governor Regulation No. 53 of 2021 on Accelerating Beef Cattle Self-Sufficiency through Oil Palm Cattle Integration Based on Inti-Plasma Partnership also support this program (Abdalla et al., 2018). To foster the sustainable advancement of agriculture, it is essential to harmonize the laws and regulations governing agricultural projects, enhance the return mechanism, bolster implementation assistance, refine the risk assessment and management of agricultural projects (Hu et al., 2024).

Another strategic initiative is the application of technology to process cattle or oil palm waste, alongside the use of waste or by-products derived from oil palm plantations, including empty fruit bunches or palm fiber, which can be effectively used as animal feed. Cattle absorb and digest these wastes, thereby effectively meeting nutritional needs. This technique helps reduce dependence on other feed sources and contributes to waste management in oil palm plantations. According to Devendra (2011, 2012), cattle grazing and shrub cover are associated with increased fertilization resulting from the application of cow dung. This fertilization process increases soil organic carbon storage and total nitrogen content. Most of the nutrients obtained by cattle from pastures are reintroduced into soil through urine and manure excretion. Furthermore, improved accessibility to soil nutrients transported by manure will benefit oil palm farmers. Incorporating cattle and oil palm through nutrient recycling reduces the dependence on synthetic fertilizers for crop

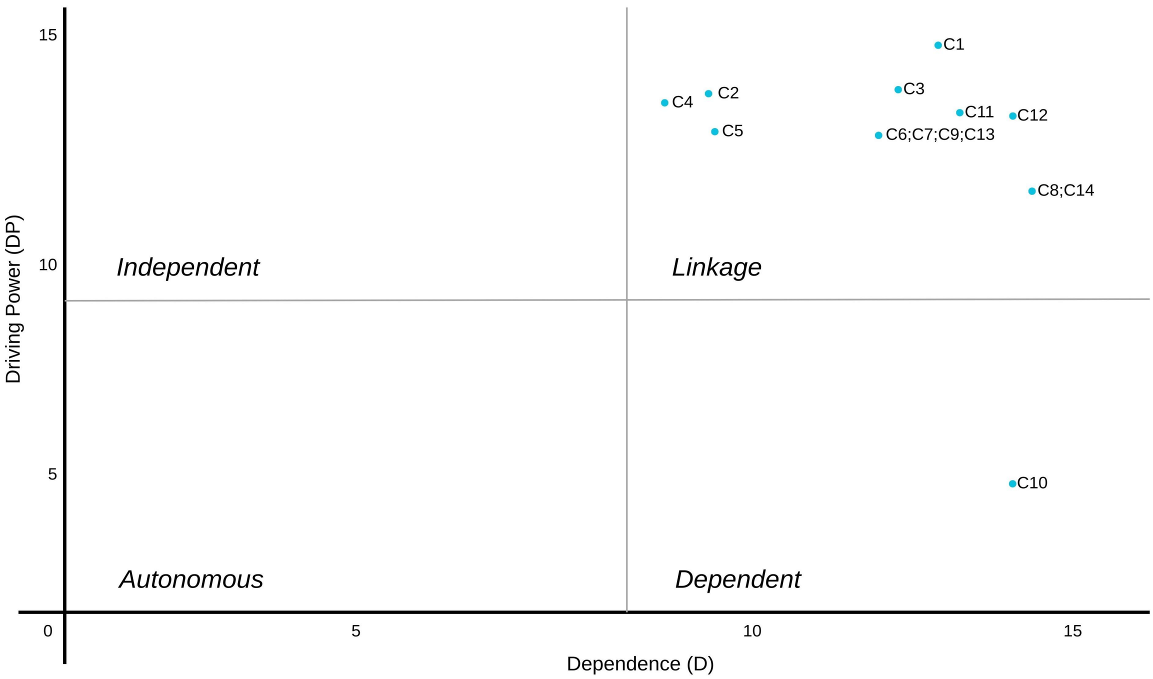

Figure 5. MICMAC strategies for the development of cattle-oil palm integration system

cultivation. Ruminant animals, such as cattle, contribute to maintaining and improving soil fertility through the production of manure (Inanda et al., 2025). Therefore, companies are encouraged to establish forums with growth leaders and farmers, conduct regular evaluations, and adapt to environmental changes to ensure alignment and effectiveness.

The formation of a specialized SISKA development team requires the participation of facilitators who play an important role in the development of the SISKA Partnership in oil palm sector. Facilitators play an important role in the success and sustainability of cattle-oil palm partnership system by fostering partnerships, mentoring and training farmers, monitoring and evaluation, as well as providing access to resources and technology. According to Saxena and Mohan (2021), support from various parties is needed to strengthen group institutions in terms of easy access to financing and to increase the capacity as well as success of group members (Qonita et al., 2025). Agricultural extension services must be customized to meet the requirements of millennial farmers, using interactive and technology-driven approaches. The media function can be augmented by creating targeted channels, such as social media, agricultural applications, websites, blogs, and videos, pertinent to their needs.

The next strategic initiative is to provide financial assistance by using existing resources and assistance mechanisms, including micro credit program capital, input, and marketing assistance. Cluster members have the opportunity to get financial assistance through the micro credit program to establish partnerships with government-affiliated banks, including Bank Rakyat Indonesia (BRI), Bank Mandiri, Bank Tabungan Negara (BTN), and Bank Negara Indonesia (BNI). According to Jafar et al. (2021), the provision of money through micro credit program access enables SISKA Partnership (cluster) farmer group management to improve the welfare of members by facilitating increased yields, income, and overall quality of life.

At the third level, there are programs, including the Inter-Institutional Collaboration Improvement Program, aimed at achieving the success of Indonesia's cattle-wheat integration system. This can be achieved through the recommended reforms to strengthen farmers in an integrated institutional setting, where independent cooperatives play a crucial role. Independent cooperatives are formed based on farmers' needs and awareness. This institutional form will be efficient when there are norms that must be obeyed by all cooperative members. According to Saxena et al. (1992), institutional strengthening of independent cattle breeders also requires support from various parties in line with the roles and duties of each actor, such as independent farmers, farmer group associations, research centers, banks, agriculture and plantation offices, cooperatives, small and medium enterprises (SMEs), and private companies.

This strategic initiative aims to increase the capacity and competence of the cluster by enhancing optimal education and training in managing oil palm plantations and cattle farms. The required technical competencies cover several areas, including plantation, cattle breeding, feed, livestock breeding, animal health, and waste management. Various strategies can facilitate the advancement of breeders and growers in the industry. These strategies include training and education, mentoring, guidance, research and innovation, resources and access to information, networking, and collaboration. Breeders and growers must be encouraged to actively participate in networking and collaboration with practitioners, experts, and other stakeholders in the industry. The current activity is an educational platform to enhance knowledge and understanding of the livestock business management process in oil palm land,

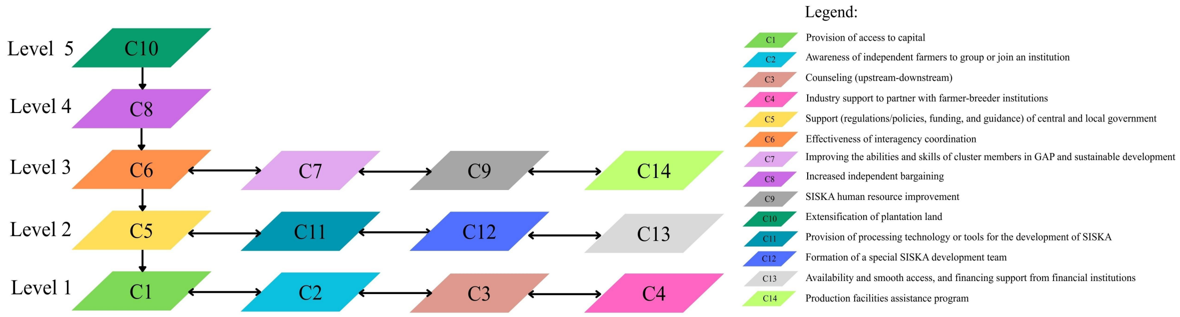

Figure 6. ISM hierarchical structure of program strategy

the animal feed industry using oil palm-derived by-products, and oil palm plantation business for grazing purposes (Utomo and Widjaja, 2020; Wulandari and Villano, 2021).

Human resource enhancement in SISKA framework plays an important role in advancing an integrated system for oil palm cattle farming in Indonesia (Dewi et al., 2022; Majesty et al., 2024; Rohaeni et al., 2025). This initiative aims to enhance the competence and character of human resources in the system. Improved technical skills, ecological awareness, managerial skills, dedication to innovation and technology, and strong teamwork will strengthen the integrated system. The presence of capable and certified human resources is expected to improve the productivity, efficiency, and sustainability of oil palm industry in Indonesia. Improved technical proficiency and optimization of cattle-oil palm integration systems are also important. A previous study by Cramb and Sujang (2013) mentioned that enhancing the technological capabilities of oil palm farmers and breeders is essential to increase proficiency. The ability to incentivize smallholders and increase productivity can be achieved by implementing institutional innovations, including the establishment of a comprehensive governance framework that covers many aspects such as land use and market activities.

Production assistance is a fast-rising strategic initiative. To accelerate the implementation of SISKA KUINTIP in South Kalimantan, the Provincial Government, in collaboration with the Plantation and Livestock Service Office, provided assistance in the form of electric fence devices. This device serves to confine livestock to a predetermined area, providing technical information on the use of electric fences and livestock-colony management. Saxena and Mohan (2021) mentioned that to improve institutional capacity, the government can contribute by implementing programs to facilitate the distribution of production inputs and provide agricultural inputs through grant initiatives (Arsyad et al., 2020). The revealed comparative advantage (RCA) value of Indonesian crude palm oil (CPO) showed a downward trend, but remains larger compared to Malaysia, which displays a positive trend. Indonesian refined, bleached, and deodorized (RBC) palm olein and palm fatty acid distillate (PFAD) demonstrated a favorable trend compared to Malaysia. Using the product mapping approach showed that oil palm from both nations was categorized in Group A, suggesting that these items have comparative advantages and export specializations. Consequently, there is a need for strategic policies in both nations to assist downstream oil palm operations. This will improve the manufacturing of derivative items capable of satisfying the demands of international trade.

At the fourth level, there is a program known as improving bargaining position (independent bargaining). This program is important and meant to be implemented in Poktan and Pokbun institutions. However, institutions are currently in a weak state, which weakens farmers' bargaining power when dealing with the prevailing market system. The results show that economic variables influence decision-making regarding plantations, thereby increasing the prospect of expanding the integration of oil palm cultivation and cattle rearing in the region. The challenges associated with the integration of oil palm and cattle pose significant barriers to plantations in terms of marketing cattle. The selling price achieved is lower than the prevailing market price, while the costs incurred in implementing the program exceed its cost base. Consequently, operations suffer financial losses (Raharja et al., 2020). An institutional model of SISKA was designed to improve farmers' bargaining power. The model requires a collaborative arrangement between farmer organizations, processing industries, and other relevant stakeholders. These components include farmers, farmer groups, farmer associations, industry, financing institutions, extension services, the government, universities, development institutions, and related agencies. In this model, farmer organizations assume an important role as collective marketing entities that operate at the district level to increase bargaining power in interactions with processing and export companies.

At the fifth level, there is the plantation expansion program, which is explicitly designed for extensification. Extensification refers to clearing land adjacent to oil palm plantations for livestock grazing using a rotational grazing approach. Companies are expected to play an important role in advancing the oil palm industry, which has the potential to make substantial contributions to economic growth and community development. However, the sustainable management of the difficulties resulting from environmental and social impacts requires an approach that emphasizes partnership and collaboration. In this particular setting, SISKA presents a potentially beneficial framework that combines the agriculture and oil palm plantation industries to achieve sustainability and increased productivity. To achieve the successful implementation, the optimization of Corporate Social Responsibility (CSR) programs by oil palm companies plays an important role. CSR helps facilitate business engagement in sustainable development and generate beneficial influences on society and the environment.

In this architecture, the position of "Plantation Land Extensification" (C10) as a lowest-level, dependent program has important conceptual and policy implications. First, it indicates that land expansion for cattle-oil palm integration is not a precondition for system development, but a potential outcome once institutional, financial, and capacity-related constraints have been addressed. In other words, ISM-MICMAC results do not support a strategy prioritizing the opening of new land as the main entry point for SISKA but suggest that stakeholders should focus on governance strengthening, smallholder support, and technical innovation in the existing plantation footprint. Land extensification would only become technically feasible and economically rational after successfully implementing these higher-level programs. The results directly contribute to debates on sustainable intensification against extensification in livestock–crop systems, where empirical work has emphasized the centrality of institutions, incentives, and knowledge systems over simple land-area expansion (Bremer et al., 2020; Álvarez et al., 2024).

Second, in response to the reviewer's concern, the inclusion of a plantation extensification strategy in a palm-oil context is highly sensitive given Indonesia's and global commitments to deforestation-free supply chains. The National Action Plan for Sustainable Oil Palm (RAN-KSB) in Indonesia, enacted through Presidential Instruction (INPRES) No. 6 of 2019 for the period 2019-2024, explicitly aims to improve land legality, and strengthen smallholder capacity, it also enhance environmental management and monitoring, while providing a coordinated framework across 14 ministries and sub-national governments for more sustainable oil palm expansion and management. In addition, South Kalimantan Provincial Regulation No. 2 of 2013 on Sustainable Plantation, South Kalimantan Governor Regulation No. 53 of 2021 on Accelerating Beef Cattle Self-Sufficiency through Oil Palm Cattle Integration Based on Inti-Plasma also support the program (Abdalla et al., 2018).

In parallel, international standards such as the 2018 Principles and Criteria of the Roundtable on Sustainable Oil palm (RSPO) (Larsen et al., 2018; Ilyas et al., 2022) integrate the high carbon stock approach (HCSA) and require the protection of high conservation value (HCV) and high carbon stock (HCS) forests, prohibit new planting on peat, and tighten social and human-rights safeguards. In the private sector, many major traders and downstream companies have adopted "No Deforestation, No Peat, No Exploitation" (NDPE) policies, which commit to eliminating deforestation and peat conversion across oil palm supply chains (Larsen et al., 2018; Ilyas et al., 2022). C10 cannot be interpreted as a recommendation for unconstrained expansion of plantation area, particularly not into forests, peatlands, or other high-conservation-value ecosystems. Instead, ISM-MICMAC result identifying C10 as a dependent, lowest-level program indicates that any form of extensification must be narrowly defined and strictly governed by sustainability safeguards. In line with RAN-KSB and RSPO/NDPE frameworks, plantation land extensification is the controlled use of legally verified, non-forest, degraded, or already-cleared land in the broader plantation landscape, after rigorous environmental and social assessments. This interpretation is consistent with recent policy analyses that emphasize the need to channel any future oil palm growth toward degraded lands and to strengthen regional action plans (RAD-KSB) as tools for steering development away from remaining natural forests.

The low driving power and hierarchical position of C10 reinforce a cautious sequencing principle, showing that SISKA stakeholders should first invest in governance, data, and coordination, then in smallholder capacity and access to finance. Only after these foundational elements are in place and only where justified, should limited extensification on degraded land be considered, supported by strong monitoring and certification systems. This approach is consistent with the model structural insights with the normative requirements of sustainable oil palm production. It also addresses concerns by explaining that "Plantation Land Extensification" in the context of this study is not synonymous with deforestation, but is conceptually restricted to degraded land in compliance with national regulations and international sustainability standards. Consequently, the results support a development pathway in which the scaling up of cattle-oil palm integration is driven primarily by institutional strengthening, technological innovation, and smallholder empowerment; any land-based expansion remains a conditional, carefully regulated, and environmentally constrained option rather than a central strategy.

Recommendations and policy implications

An integrated cattle-oil palm system can facilitate Indonesia's attainment of beef self-sufficiency while promoting sustainable oil palm practices. Success on government assistance, private sector participation, and farmer adoption. Essential policies must prioritize financial incentives, environmental conservation, and enhancements in supply chain efficiency to guarantee sustainability. Financial incentives should be provided to smallholder farmers who implement integrated cattle-oil palm production. Stakeholders should also partner with universities and agricultural technology firms to educate farmers on sustainable integration methods. Tax incentives are needed for enterprises in the integration of cattle and oil palms. Additionally, cooperatives that connect oil palm cultivators with cattle producers should be established to optimize feed and beef supply chains. These collaborative efforts will not only bolster local economies but also promote biodiversity by ensuring that agricultural practices are productive and environmentally friendly.

By fostering a supportive ecosystem for farmers, Indonesia can create a model of sustainable agriculture that benefits both communities and the world. Private sector investment should also be encouraged in integrated processing facilities for palm-derived animal feed and beef products. More resources should be allocated for further studies and the development of extremely nutritious palm-derived animal feed. The adoption of digital surveillance systems, such as Internet of Things (IoT) for monitoring animal health and satellites for assessing land utilization, would enhance system transparency, improve management, and ensure compliance with sustainability standards.

CONCLUSIONS

The results show that institutional constraints, particularly weak coordination, leadership limitations, inadequate human resources, and unclear organizational roles, remain the main inhibitors of cattle oil palm integration. ISM hierarchical model identifies 14 strategic programs, with the most influential being inter-agency collaboration, upstream-downstream extension services, financial access, cooperative strengthening, and technology provision. These elements function as leverage points to enhance institutional performance and reinforce the overall integration system. Strengthening cooperatives as the central coordinating institution is essential to unite farmers, companies, and government agencies. Harmonized regulations, sustainable funding, and incentives for private-sector are essential to improve supply-chain efficiency and environmental stewardship.

ACKNOWLEDGEMENT

This study was funded by the Scheme of Thematic Research Group (TRG) Batch-1, Hasanuddin University, Indonesia, under the Decree No. 00518/UN4.22/PT.01.03/2025, dated February 14, 2025. Thanks to the Research Institute and Community Services (LPPM), Hasanuddin University for technical support during the research period.

REFERENCES

Abdalla, M., Hastings, A., Chadwick, D. R., Jones, D. L., Evans, C. D., Jones, M. B., ... & Smith, P. E. T. E. (2018). Critical review of the impacts of grazing intensity on soil organic carbon storage and other soil quality indicators in extensively managed grasslands. *Agriculture, Ecosystems & Environment*, *253*, 62–81. https://doi.org/10.1016/j.agee.2017.10.023

Abid, M., Ngaruiya, G., Scheffran, J., & Zulfiqar, F. (2017). The role of social networks in agricultural adaptation to climate change: Implications for sustainable agriculture in Pakistan. *Climate*, *5*(4), 85. https://doi.org/10.3390/cli5040085

Agrawal, N. M. (2019). Modeling Deming's quality principles to improve performance using interpretive structural modeling and MICMAC analysis. *International Journal of Quality and Reliability Management*, *36*(7), 1159–1180. https://doi.org/10.1108/IJQRM-07-2018-0204

Ahmad, N. (2024). SmartISM 2.0: A roadmap and system to implement fuzzy ISM and fuzzy MICMAC. *Sustainability (2071-1050)*, *16*(20), 8873. https://doi.org/10.3390/su16208873

Ahmadzai, H., Tutundjian, S., & Elouafi, I. (2021). Policies for sustainable agriculture and livelihood in marginal lands: A review. *Sustainability*, *13*(16), 8692. https://doi.org/10.3390/su13168692

Ali, M. S. S., Nikoyan, A., Salman, D., Demmalino, E. B., & Summase, I. (2015). Multi-actors collaboration in ecolabelling community teak forest management in Southeast Sulawesi Province, Indonesia. *International Journal of Agriculture System*, *3*(1), 91–102. https://doi.org/10.20956/ijas.v3i1.51

Ali, P. R., Machfud, M., Sukardi, S., Noor, E., & Purnomo, D. (2023). Indonesian agroindustry business agility: Enablers and challenges in the poultry industry based on ISM model. *Heliyon*, *9*(6), e16808. https://doi.org/10.1016/j.heliyon.2023.e16808

Álvarez, E. R., Castiblanco, J. S., & Montoya, M. M. (2024). Sustainable intensification of palm oil production through cattle integration: A review. *Agroecology and Sustainable Food Systems*, *48*(3), 313–331. https://doi.org/10.1080/21683565.2023.2299012

Arsyad, M., Amiruddin, A., Suharno, & Jahroh, S. (2020). Competitiveness of palm oil products in international trade: An analysis between Indonesia and Malaysia. *Caraka Tani: Journal of Sustainable Agriculture*, *35*(2), 157–167. https://doi.org/10.20961/carakatani.v35i2.41091

Attri, R., Dev, N., & Sharma, V. (2013). Interpretive structural modelling (ISM) approach: An overview. *Research Journal of Management Sciences*, *2319*(2), 1171. Retrieved from https://www.isca.in/IJMS/Archive/v2/i2/2.ISCA-RJMS-2012-054.php

Azhar, B., Tohiran, K. A., Nobilly, F., Zulkifli, R., Syakir, M. I., Ishak, Z., ... & Maxwell, T. M. (2021). Time to revisit oil palm-livestock integration in the wake of United Nations Sustainable Development Goals (SDGs). *Frontiers in Sustainable Food Systems*, *5*, 640285. https://doi.org/10.3389/fsufs.2021.640285

Baharim, M. S., Adnan, N. A., Mohd, F. A., Seman, I. A., Izzuddin, M. A., & Aziz, N. A. (2022). A review: Progression of remote sensing (RS) and geographical information system (GIS) applications in oil palm management and sustainability. *IOP Conference Series: Earth and Environmental Science*, *1051*(1), 012027. https://doi.org/10.1088/1755-1315/1051/1/012027

Baliarti, E., Budisatria, I. G. S., Atmoko, B. A., & Maulana, H. (2020). Calf production of Bali cows in cattle-oil palm plantation integration system in Riau Province Indonesia. *IOP Conference Series: Earth and Environmental Science*, *518*(1), 012015. https://doi.org/10.1088/1755-1315/518/1/012015

Barati, A. A., Azadi, H., Pour, M. D., Lebailly, P., & Qafori, M. (2019). Determining key agricultural strategic factors using AHP-MICMAC. *Sustainability*, *11*(14), 3947. https://doi.org/10.3390/su11143947

Bremer, J. A., Lobry de Bruyn, L. A., Smith, R. G., & Cowley, F. C. (2022a). Knowns and unknowns of cattle grazing in oil palm plantations. A review. *Agronomy for Sustainable Development*, *42*(2), 17. https://doi.org/10.1007/s13593-021-00723-x

Bremer, J. A., Lobry de Bruyn, L. A., Smith, R. G. B., Darsono, W., Soedjana, T. D., & Cowley, F. C. (2022b). Prospects and problems: Considerations for smallholder cattle grazing in oil palm plantations in South Kalimantan, Indonesia. *Agroforestry Systems*, *96*(7), 1023–1037. https://doi.org/10.1007/s10457-022-00759-2

Bremer, S., Johnson, E., Fløttum, K., Kverndokk, K., Wardekker, A., & Krauß, W. (2020). Portrait of a climate city: How climate change is emerging as a risk in Bergen, Norway. *Climate Risk Management*, *29*, 100236. https://doi.org/10.1016/j.crm.2020.100236

Brown, K., Schirmer, J., & Upton, P. (2021). Regenerative farming and human wellbeing: Are subjective wellbeing measures useful indicators for sustainable farming systems? *Environmental and Sustainability Indicators*, *11*, 100132. https://doi.org/10.1016/j.indic.2021.100132

Cramb, R. A., & Sujang, P. S. (2013). The mouse deer and the crocodile: Oil palm smallholders and livelihood strategies in Sarawak, Malaysia. *Journal of Peasant Studies*, *40*(1), 129–154. https://doi.org/10.1080/03066150.2012.750241

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches*. USA: Sage Publications. Retrieved from https://scholar.

google.co.id/scholar?cites=5941254364905912610&as_sdt=2005&sciodt=0,5&hl=id

Devendra, C. (2011). Integrated tree crops-ruminants systems in South East Asia: Advances in productivity enhancement and environmental sustainability. *Asian-Australasian Journal of Animal Sciences*, *24*(5), 587–602. https://doi.org/10.5713/ajas.2011.r.07

Devendra, C. (2012). Review - Rainfed areas and animal agriculture in Asia: The wanting agenda for transforming productivity growth and rural poverty. *Asian-Australasian Journal of Animal Sciences*, *25*(1), 122–142. https://doi.org/10.5713/ajas.2011.r.09

Dewi, R. R., Hassan, L., Daud, H. M., Matori, M. F., Zakaria, Z., Ahmad, N. I., ... & Jajere, S. M. (2022). On-farm practices associated with multi-drug-resistant *Escherichia coli* and *Vibrio parahaemolyticus* derived from cultured fish. *Microorganisms*, *10*(8), 1520. https://doi.org/10.3390/microorganisms10081520

Dharmawan, A. H., Mardiyaningsih, D. I., Komarudin, H., Ghazoul, J., Pacheco, P., & Rahmadian, F. (2020). Dynamics of rural economy: A socio-economic understanding of oil palm expansion and landscape changes in East Kalimantan, Indonesia. *Land*, *9*(7), 213. https://doi.org/10.3390/land9070213

Firmansya, Suparjo, Novianti, S., & Maruli, P. (2022). Development of cattle integration in various patterns of maintenance with smallholder oil palm plantations. *Journal of Southwest Jiaotong University*, *57*(5), 427–444. https://doi.org/10.35741/issn.0258-2724.57.5.34

Han, C., Zhang, H., & Zhang, Y. (2025). Balancing growth and preservation: Strategic pathways for sustainable rural tourism in China’s environmental landscape. *Sustainability*, *17*(1), 246. https://doi.org/10.3390/su17010246

Hospes, O., Kroeze, C., Oosterveer, P., Schouten, G., & Slingerland, M. (2017). New generation of knowledge: Towards an inter- and transdisciplinary framework for sustainable pathways of palm oil production. *Njas-Wageningen Journal of Life Sciences*, *80*(1), 75–84. https://doi.org/10.1016/J.NJAS.2017.01.001

Hu, Q., Entebang, H., & Puah, C. H. (2024). Status and development of agricultural public-private partnership program implementation in China. *Caraka Tani: Journal of Sustainable Agriculture*, *39*(1), 223–234. https://doi.org/10.20961/carakatani.v39i1.83311

Ilyas, R. A., Sapuan, S. M., Ibrahim, M. S., Wondi, M. H., Norrrahim, M. N. F., Harussani, M. M., ... & Haris, N. I. N. (2022). Policy and environmental aspects of oil palm biomass. *Oil Palm Biomass for Composite Panels* (pp. 339–351). https://doi.org/10.1016/B978-0-12-823852-3.00001-5

Inanda, D. S., Laksono, P., Suryantini, A., & Utami, A. W. (2025). Stakeholders hybrid maize production in Indonesia. *Caraka Tani: Journal of Sustainable Agriculture*, *40*(1), 139–155. https://doi.org/10.20961/carakatani.v40i1.88996

Inumula, K. M., Singh, S., & Solanki, S. (2020). Energy consumption and agricultural economic growth nexus: Evidence from India. *International Journal of Energy Economics and Policy*, *10*(6), 545–552. https://doi.org/10.32479/ijeep.9711

Jafar, R., Nuddin, A., Khaerunnisa, & MacHmuddin, N. (2021). Institutional systems in planning and strategy for oyster mushroom business development. *IOP Conference Series: Earth and Environmental Science*, *748*(1), 012019. https://doi.org/10.1088/1755-1315/748/1/012019

Jelsma, I., Schoneveld, G. C., Zoomers, A., & van Westen, A. C. M. (2017). Unpacking Indonesia’s independent oil palm smallholders: An actor-disaggregated approach to identifying environmental and social performance challenges. *Land Use Policy*, *69*, 281–297. https://doi.org/10.1016/j.landusepol.2017.08.012

Judijanto, L. (2025). Decarbonising the palm oil value chain: A review of sustainability certifications, policy alignment, and technological readiness for net-zero targets. *Seven Editora*, 1416–1438. https://doi.org/10.56238/sevened2025.021-084

Kabir, J., Cramb, R., Alauddin, M., Gaydon, D. S., & Roth, C. H. (2020). Farmers’ perceptions and management of risk in rice/shrimp farming systems in South-West Coastal Bangladesh. *Land Use Policy*, *95*, 104577. https://doi.org/10.1016/j.landusepol.2020.104577

Kassam, A., Friedrich, T., & Derpsch, R. (2019). Global spread of conservation agriculture. *International Journal of Environmental Studies*, *76*(1), 29–51. https://doi.org/10.1080/00207233.2018.1494927

Kumar, G., Bhujel, R. C., Aggarwal, A., Gupta, D., Yadav, A., & Asjad, M. (2023). Analyzing the barriers for aquaponics adoption using integrated BWM and fuzzy DEMATEL approach in Indian context. *Environmental Science and Pollution Research*, *30*(16), 47800–47821. https://doi.org/10.1007/s11356-023-25561-0

Larsen, R. K., Osbeck, M., Dawkins, E., Tuhkanen, H., Nguyen, H., Nugroho, A., ... & Wolvekamp, P. (2018). Hybrid governance in agricultural commodity chains: Insights from implementation of 'No Deforestation, No Peat, No Exploitation' (NDPE) policies in the oil palm industry. *Journal of Cleaner Production*, *183*, 544–554. https://doi.org/10.1016/j.jclepro.2018.02.125

Lee, J. S. H., Ghazoul, J., Obidzinski, K., & Koh, L. P. (2014). Oil palm smallholder yields and incomes constrained by harvesting practices and type of smallholder management in Indonesia. *Agronomy for Sustainable Development*, *34*(2), 501–513. https://doi.org/10.1007/s13593-013-0159-4

Majesty, K. I., Purnamasari, B. D., Mizuno, K., Sutardi, T., & Ekawati, K. N. (2024). Palm oil waste management with local wisdom as an approach to achieve sustainable development in independent smallholder palm plantations. *Evergreen*, *11*(4), 3484–3496. https://doi.org/10.5109/7326984

Marks, S. (2017). Institutional responses to pressures for sustainable palm oil. *EnviroLab Asia*, *1*(3), 9. Retrieved from https://scholarship.claremont.edu/envirolabasia/vol1/iss3/9/

Ogahara, Z., Jespersen, K., Theilade, I., & Nielsen, M. R. (2022). Review of smallholder palm oil sustainability reveals limited positive impacts and identifies key implementation and knowledge gaps. *Land Use Policy*, *120*, 106258. https://doi.org/10.1016/j.landusepol.2022.106258

Plantation and Livestock Service of South Kalimantan. (2024). *Sistem integrasi sawit sapi berbasis inti-plasma (SISKA KUINTIP) Kalimantan Selatan*. Retrieved from https://diskominfomc.kalselprov.go.id/2024/07/15/program-unggulan-siska-ku-intip-jadi-role-model-pengembangan-integrasi-kelapa-sawit-sapi/

Qonita, R. R. A., Masyhuri, Jamhari, & Perwitasari, H. (2025). Social environmental support in encouraging entrepreneurial behavior of millennial farmers in the Special Region of Yogyakarta, Indonesia: An effort to realize sustainable agriculture. *Caraka Tani: Journal of Sustainable Agriculture*, *40*(1), 64–83. https://doi.org/10.20961/carakatani.v40i1.92724

Quttainah, M. A., & Singh, P. (2024). The enablers and interdependencies of blockchain technology in supply chain management: Evidence from luxury products. *Thunderbird International Business Review*, *66*(6), 655–666. https://doi.org/10.1002/tie.22408

Rachman, T., Marimin, M., Ismayana, A., & Sugiarto, S. (2024). Model development of a downstreaming policy for crude palm oil for domestic and export needs: A systematic literature review and future agendas. *BIO Web of Conferences*, *123*, 4003. https://doi.org/10.1051/bioconf/202412304003

Rade, K. A., Pharande, V. A., & Saini, D. R. (2017). Interpretive structural modeling (ISM) for recovery of heat energy. *International Journal of Theoretical and Applied Mechanics*, *12*(1), 83–92. Retrieved from https://www.ripublication.com/ijtam17/ijtamv12n1_08.pdf

Raharja, S., Marimin, Machfud, Papilo, P., Safriyana, Massijaya, M. Y., … & Darmawan, M. A. (2020). Institutional strengthening model of oil palm independent smallholder in Riau and Jambi Provinces, Indonesia. *Heliyon*, *6*(5), e03875. https://doi.org/10.1016/j.heliyon.2020.e03875

Raisa, D. M., Sirajuddin, S. N., Syamsu, J. A., & Arsyad, M. (2024). Analysis of strategic programs in planning and developing cattle-oil palm integration system. *IOP Conference Series: Earth and Environmental Science*, *1364*(1), 012012. https://doi.org/10.1088/1755-1315/1364/1/012012

Rohaeni, E. S., Darsani, Y. R., Qomariah, R., Darwis, V., Lesmayati, S., Bahua, H., ... & Krisdiana, R. (2025). Sustainability index analysis for integration of oil palm and cattle gender-based in tidal land. *Sustainable*

Futures, *10*, 100931. https://doi.org/10.1016/j.sftr.2025.100931

Rosada, I., Nurliani, N., Amiruddin, A., & Novanda, R. R. (2025). Identifying constraints and strategies for palm oil production in Indonesia: An interpretive structure model approach. *Asian Journal of Agriculture and Rural Development*, *15*(2), 134–144. https://doi.org/10.55493/5005.v15i2.5368

Saxena, A., & Mohan, S. B. (2021). The impact of food security disruption due to the Covid-19 pandemic on tribal people in India. *Advances in Food Security and Sustainability*, *6*, 65–81. Elsevier Inc. https://doi.org/10.1016/bs.af2s.2021.07.006

Saxena, J. P., Sushil, & Vrat, P. (1992). Hierarchy and classification of program plan elements using interpretive structural modeling: A case study of energy conservation in the Indian cement industry. *Systems Practice*, *5*(6), 651–670. https://doi.org/10.1007/BF01083616

Schut, M., Klerkx, L., Rodenburg, J., Kayeke, J., Hinnou, L. C., Raboanarielina, C. M., ... & Bastiaans, L. (2015). RAAIS: Rapid appraisal of agricultural innovation systems (Part I). A diagnostic tool for integrated analysis of complex problems and innovation capacity. *Agricultural Systems*, *132*, 1–11. https://doi.org/10.1016/j.agsy.2014.08.009

Shahzad, H. M. A., Almomani, F., Shahzad, A., Mahmoud, K. A., & Rasool, K. (2024). Challenges and opportunities in biogas conversion to microbial protein: A pathway for sustainable resource recovery from organic waste. *Process Safety and Environmental Protection*, *185*, 644–659. https://doi.org/10.1016/j.psep.2024.03.055

Sihombing, W. P., Hanafi, N. D., & Rahmanta. (2020). Analysis of factor that influences decision making for the implementation of the integration system of oil palm and cattle in Serdang Bedagai Regency plantations. *IOP Conference Series: Earth and Environmental Science*, *454*(1), 012051. https://doi.org/10.1088/1755-1315/454/1/012051

Silalahi, F. R. L., Rauf, A., Hanum, C., & Siahaan, D. (2019). Swot analysis of development of beef cattle - Palm oil integration in Indonesia. *IOP Conference Series: Earth and Environmental Science*, *347*(1), 012105. https://doi.org/10.1088/1755-1315/347/1/012105

Singh, C., Rahman, A., Srinivas, A., & Bazaz, A. (2018). Risks and responses in rural India: Implications for local climate change adaptation action. *Climate Risk Management*, *21*, 52–68. https://doi.org/10.1016/j.crm.2018.06.001

Singh, D., Biswal, A. K., Samanta, D., Singh, V., Kadry, S., Khan, A., & Nam, Y. (2023). Smart high-yield tomato cultivation: Precision irrigation system using the Internet of Things. *Frontiers in Plant Science*, *14*, 1239594. https://doi.org/10.3389/fpls.2023.1239594

Singh, P. (2020). Role of blockchain technology in digitization of land records in Indian scenario. *IOP Conference Series: Earth and Environmental Science*, *614*(1), 012055. https://doi.org/10.1088/1755-1315/614/1/012055

Soliman, T., Lim, F. K. S., Lee, J. S. H., & Carrasco, L. R. (2016). Closing oil palm yield gaps among Indonesian smallholders through industry schemes, pruning, weeding and improved seeds. *Royal Society Open Science*, *3*(8), 160292. https://doi.org/10.1098/rsos.160292

Supriatna, J., Djumarno, D., Saluy, A. B., & Kurniawan, D. (2024). Sustainability analysis of smallholder oil palm plantations in several provinces in Indonesia. *Sustainability*, *16*(11), 4383. https://doi.org/10.3390/su16114383

Udayana, I. B. K., Eriyatno, Hambali, E., & Fauzi, A. M. (2010). *Manajemen risiko agroindustri biodiesel berbasis kelapa sawit (Dissertations)*. Bogor, Indonesia: IPB University. Retrieved from http://repository.ipb.ac.id/handle/123456789/55055

Umar, Y., Syakir, M. I., Yusuff, S., Azhar, B., & Tohiran, K. A. (2023). The integration of cattle grazing activities as potential best sustainable practices for weeding operations in oil palm plantations. *IOP Conference Series: Earth and Environmental Science*, *1167*(1), 012014. https://doi.org/10.1088/1755-1315/1167/1/012014

Utomo, B. N., & Widjaja, E. (2020). The activities of the integration of oil palm and cattle (ISAPI) by group of farmer and its development strategy in Lamandau District, Central Kalimantan Province. *IOP Conference Series: Earth and Environmental Science*, *492*(1), 012062. https://doi.org/10.1088/1755-1315/492/1/012062

Vendramini, J. M. B., & Moriel, P. (2018). Forage management and concentrate supplementation effects on performance of beef calves. *Animal Production Science*, *58*(8), 1399–1403. https://doi.org/10.1071/AN17797

Wulandari, S., & Villano, R. (2021). Strategies to optimize women's participation in palm cattle integration. *IOP Conference Series: Earth and Environmental Science*, *694*(1), 012014. https://doi.org/10.1088/1755-1315/694/1/012014

Yuhendra, Y., Syaukat, Y., Hartoyo, S., & Kusnadi, N. (2022). Analysis of farmer perceptions in adopting the integrated farming system: A case study of oil palm plantation in Riau Province. *Jurnal Manajemen & Agribisnis*, *19*(2), 165–165. https://doi.org/10.17358/jma.19.2.165

Appendix 1. Initial SSIM sub-element challenges

Sub-element challenges	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13
B1		V	X	V	X	X	A	V	V	V	X	V	X
B2			A	A	A	A	A	A	A	X	A	A	A
B3				V	X	X	X	X	V	V	A	V	V
B4					A	V	A	V	V	V	A	A	A
B5						V	A	A	V	V	A	V	V
B6							V	V	A	A	A	A	A
B7								V	V	X	X	X	X
B8									V	V	X	X	X
B9										X	A	X	A
B10											A	X	X
B11												X	X
B12													X
B13													

Appendix 2. Reachability matrix (RM) describes challenges in SISKA development

Sub-element challenges	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13
B1	1	1	1	1	1	1	0	1	1	1	1	1	1
B2	0	1	0	0	0	0	0	0	0	1	0	0	0
B3	1	1	1	1	1	1	1	1	1	1	0	1	1
B4	0	1	0	1	0	1	0	1	1	1	0	0	0
B5	1	1	1	1	1	1	0	0	1	1	0	1	1
B6	1	1	1	0	0	1	1	1	0	0	0	0	0
B7	1	1	1	1	1	0	1	1	1	1	1	1	1
B8	0	1	1	0	1	0	0	1	1	1	1	1	1
B9	0	1	0	0	0	1	0	0	1	1	0	1	0
B10	0	1	0	0	0	1	1	0	1	1	0	1	1
B11	1	1	1	1	1	1	1	1	1	1	1	1	1
B12	0	1	0	1	0	1	1	1	1	1	1	1	1
B13	1	1	0	1	0	1	1	1	1	1	1	1	1

Appendix 3. Final reachability matrix (RM)

Sub-element challenges	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13
B1	1	1	1	1	1	1	1	1	1	1	1	1	1
B2	0	1	0	0	0	0	0	0	0	1	0	1	1
B3	1	1	1	1	1	1	1	1	1	1	1	1	1
B4	0	1	0	1	0	1	1	1	1	1	1	1	1
B5	1	1	1	1	1	1	1	1	1	1	0	1	1
B6	1	1	1	0	0	1	1	1	1	1	1	1	1
B7	1	1	1	1	1	0	1	1	1	1	1	1	1
B8	0	1	1	0	1	0	0	1	1	1	1	1	1
B9	0	1	0	0	0	1	0	0	1	1	0	1	1
B10	0	1	0	0	0	1	1	0	1	1	0	1	1
B11	1	1	1	1	1	1	1	1	1	1	1	1	1
B12	0	1	0	1	0	1	1	1	1	1	1	1	1
B13	1	1	0	1	0	1	1	1	1	1	1	1	1

Appendix 4. Canonical matrix challenges in SISKA development

Sub-element challenges	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	DP	R
B1	1	1	1	1	1	1	1	1	1	1	1	1	1	13	1
B2	0	1	0	0	0	0	0	0	0	1	0	1	1	4	8
B3	1	1	1	1	1	1	1	1	1	1	1	1	1	13	1
B4	0	1	0	1	0	1	1	1	1	1	1	1	1	10	4
B5	1	1	1	1	1	1	1	1	1	1	0	1	1	12	2
B6	1	1	1	0	0	1	1	1	1	1	1	1	1	11	3
B7	1	1	1	1	1	0	1	1	1	1	1	1	1	12	2
B8	0	1	1	0	1	0	0	1	1	1	1	1	1	9	5
B9	0	1	0	0	0	1	0	0	1	1	0	1	1	6	7
B10	0	1	0	0	0	1	1	0	1	1	0	1	1	7	6
B11	1	1	1	1	1	1	1	1	1	1	1	1	1	13	1
B12	0	1	0	1	0	1	1	1	1	1	1	1	1	10	4
B13	1	1	0	1	0	1	1	1	1	1	1	1	1	11	3
D	7	13	7	8	6	10	10	10	12	13	9	13	13		
L	6	1	6	5	7	3	3	3	2	1	4	1	1		

Note: D = Dependence, L = Level

Appendix 5. Initial SSIM sub-element strategy

Sub-element strategy	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
C1		X	X	X	X	X	X	X	X	V	X	X	X	X
C2			X	X	V	V	V	V	X	V	X	X	X	X
C3				X	X	X	X	X	X	V	X	X	X	X
C4					X	V	V	V	V	V	V	X	X	X
C5						X	X	V	V	V	X	V	V	X
C6							X	X	X	V	X	X	X	X
C7								X	X	V	X	X	X	X
C8									X	X	X	X	X	X
C9										V	X	X	X	X
C10											X	X	A	X
C11												X	X	V
C12													X	X
C13														V
C14														

Appendix 6. Reachability matrix (RM) describes the program strategy in SISKA development

Sub-element strategy	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
C1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C3	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C5	1	0	1	1	1	1	1	1	1	1	1	1	1	1
C6	1	0	1	0	1	1	1	1	1	1	1	1	1	1
C7	1	0	1	0	1	1	1	1	1	1	1	1	1	1
C8	1	0	1	0	0	1	1	1	1	1	1	1	1	1
C9	1	1	1	0	0	1	1	1	1	1	1	1	1	1
C10	0	0	0	0	0	0	0	1	0	1	1	1	0	1

Sub-element strategy	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
C11	1	1	1	0	1	1	1	1	1	1	1	1	1	1
C12	1	1	1	1	0	1	1	1	1	1	1	1	1	1
C13	1	1	1	1	0	1	1	1	1	1	1	1	1	1
C14	1	1	1	1	1	1	1	1	1	1	0	1	0	1

Appendix 7. Final reachability matrix (RM)

Sub-element strategy	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
C1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C3	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C5	1	0	1	1	1	1	1	1	1	1	1	1	1	1
C6	1	0	1	0	1	1	1	1	1	1	1	1	1	1
C7	1	0	1	0	1	1	1	1	1	1	1	1	1	1
C8	1	0	1	0	0	1	1	1	1	1	1	1	1	1
C9	1	1	1	0	0	1	1	1	1	1	1	1	1	1
C10	0	0	0	0	0	0	0	1	0	1	1	1	1	1
C11	1	1	1	0	1	1	1	1	1	1	1	1	1	1
C12	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C13	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C14	1	1	1	1	1	1	1	1	1	1	0	1	0	1

Appendix 8. Canonical matrix strategies in SISKA development

Sub-element challenges	C1	C2	3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	DP
C1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
C2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
C3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
C4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
C5	1	0	1	1	1	1	1	1	1	1	1	1	1	1	13
C6	1	0	1	0	1	1	1	1	1	1	1	1	1	1	12
C7	1	0	1	0	1	1	1	1	1	1	1	1	1	1	12
C8	1	0	1	0	0	1	1	1	1	1	1	1	1	1	11
C9	1	1	1	0	0	1	1	1	1	1	1	1	1	1	12
C10	0	0	0	0	0	0	0	1	0	1	1	1	1	1	6
C11	1	1	1	0	1	1	1	1	1	1	1	1	1	1	13
C12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13
C13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13
D	1	1	1	1	1	1	1	1	1	1	0	1	0	1	12
L	13	9	13	8	9	13	13	14	13	14	13	14	13	14	

Note: D = Dependence, L = Level