

Integrating Circular Bioeconomy and Indigenous Land Governance for Sustainable Development in Papuan Transmigration Regions

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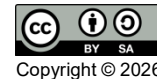
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Abstract

This study develops an integrated green economy framework for sustainable development in Indigenous Papuan transmigration areas, using the Klamono–Segun corridor in Southwest Papua, Indonesia, as a case study. Although the corridor's land-use structure is dominated by plantations and convertible production forests, opportunities to convert biomass residues into economic value remain underexplored. The study employs a descriptive qualitative design and policy-model synthesis, drawing on spatial planning documents, commodity profiles, and relevant international literature. Findings inform a framework linking two pathways: biomass waste valorization for energy production and agro-processing to increase the value of local commodities, including sago, cocoa, oil palm, rubber, and coconut. These pathways are integrated through a circular 9R framework, the One Group One Product scheme, and quadruple-helix governance. The framework's contribution lies in integrating resource efficiency, regional value creation, and customary land governance. Its implementation requires field-based biomass assessment, feasibility analysis, and meaningful participation of Indigenous customary institutions.

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1. Introduction

Transmigration in Papua presents spatial, economic, and institutional challenges that distinguish it from transmigration elsewhere in Indonesia. For Orang Asli Papua (OAP), land is not merely a productive asset; it is also a spiritual and genealogical inheritance connected to clan (fam) identity. Interventions on customary land without clan recognition may intensify disputes (Wamafma et al., 2025). These issues are evident in the Klamono–Segun corridor in Sorong Regency, Southwest Papua, covering 108,885.63 hectares across seven Development Zone Units (Satuan Kawasan Pengembangan, SKP A–G) and twenty-three villages. The Klamono New Growth Centre (KPB) serves as the main hub in a hinterland where Maybrat and Aifat customary territories overlap with planned economic activities.

The corridor's spatial allocation is strongly oriented toward commercial land uses. Plantation zones account for 45.65% of the area and convertible production-forest zones for 43.98%, whereas the food-crop zone occupies only 0.77%. Previous analyses identify a mismatch between this planning structure and OAP food-security and livelihood needs (Ibal et al., 2023; Ibal & Abubakar, 2024; Wutwensa et al., 2024). At the same time, commodity-oriented land use produces residues from oil palm,

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cocoa, sago, coconut, rubber, and forestry activities. These include empty fruit bunches, palm oil mill effluent, cocoa pod husks, sago pith and bark, coconut shells and husks, and timber offcuts, alongside village solid waste (Aprilianto & Rau, 2025; Dominic & Baidurah, 2025; Nagime et al., 2025). Yet these materials are not systematically treated as resources within the corridor's development model.

A green economy approach can connect environmental management with regional economic development rather than treating them as competing priorities. Agricultural and forestry residues and village solid waste may support refuse-derived fuel, bio-briquettes, and biogas, potentially improving rural energy access and reducing fossil-fuel reliance (Cuenca-Enrique et al., 2024; Islam et al., 2024). In parallel, processing local commodities beyond their raw or minimally processed forms could retain more value within the region. Potential pathways include sago starch, fermented cocoa, crumb rubber, copra oil, and organic fertiliser (Elida et al., 2021; Kover et al., 2022). Circular-economy research indicates that agricultural residues can also be valorised through energy recovery, material reuse, and nutrient recycling (Donner et al., 2020; Velasco-Muñoz et al., 2021). However, technical potential alone does not ensure socially legitimate development.

The central research gap is the limited integration of biomass valorisation, agro-processing, and customary land governance within a single framework tailored to an Indigenous transmigration corridor. Research on biomass and circular economy often focuses on resource conversion and environmental performance, whereas debates concerning Papua's transmigration areas emphasise land rights, livelihoods, and spatial planning. These dimensions must be integrated: development based on customary territories may be unsustainable if Indigenous institutions lack decision-making power. Research on customary land and Indigenous governance highlights the importance of rights recognition and locally grounded institutional arrangements (Azis & Alputila, 2025; Karso, 2025). Quadruple-helix collaboration offers a structure for coordinating academia, business, government, and communities, although effective implementation cannot be assumed from the model's design alone (Hakeem et al., 2023).

This study therefore develops a green-economy-based sustainable development framework for the Klamono–Segun corridor. Its objectives are to: (1) examine land-use allocation and commodity structure as a basis for identifying potential biomass-residue streams; (2) integrate biomass waste-to-energy and agro-processing value addition within a circular 9R framework and the existing One Group One Product scheme; and (3) identify implementation conditions that recognise OAP customary land rights and participation. The study draws on secondary spatial and planning documents, commodity profiles, and relevant literature to map indicative residue and value-addition pathways across the seven SKPs. As no site-specific biomass audit or field validation is undertaken, the proposed pathways constitute a planning framework requiring further technical and financial assessment. The contribution is to connect circular resource use and regional value creation with customary governance in a place-specific model that can inform future assessment and policy development in Papua and other resource-frontier regions of eastern Indonesia.

2. Literature Review

Green Economy and Sustainable Regional Development

The green economy provides a conceptual basis for integrating economic growth, environmental protection, and social inclusion within regional development strategies. Rather than pursuing economic expansion independently of ecological constraints, this approach emphasises resource efficiency, reduced environmental risks, and improved human well-being. At the regional level, green transitions can support coordinated economic development by aligning environmental objectives with economic transformation and more balanced territorial growth (Xu et al., 2024). This perspective is particularly

relevant to resource-dependent regions where economic activities rely heavily on land-intensive production and primary commodities.

In the Klamono–Segun transmigration corridor, the dominance of plantation and convertible production-forest zones presents both an economic opportunity and a sustainability challenge. Although these land uses provide a basis for commodity production, their concentration may constrain alternative land uses associated with food security and local livelihood diversification. A green economy perspective therefore requires more than improving the environmental efficiency of existing production. It also requires identifying opportunities to generate additional value from existing resources without increasing pressure on customary forests or undermining Indigenous livelihoods. In this study, the green economy serves as the overarching framework connecting biomass valorisation, agro-processing, and customary land governance. Its relevance lies in redirecting existing production systems toward resource-efficient and socially inclusive development rather than relying exclusively on further land conversion.

Biomass Valorisation and the Circular Economy

Agricultural and forestry residues represent potential economic resources when appropriate conversion technologies, infrastructure, and markets are available. In Indonesia, oil palm residues have attracted particular attention because they can support thermochemical conversion, anaerobic digestion, and other bioenergy applications. Empty fruit bunches account for approximately 20–23% of fresh fruit bunch weight, indicating the potential significance of this residue stream for resource recovery and energy production (Nabila et al., 2023; Suhartini et al., 2022). Nevertheless, the practical value of these resources depends on their availability, composition, collection costs, and suitability for particular conversion processes.

Circular economy theory extends this perspective by challenging linear production systems in which resources are extracted, processed, and discarded. Instead, it promotes strategies that retain material and economic value through reuse, recycling, recovery, and related resource-efficiency practices. The 9R framework provides a structured approach encompassing refuse, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover (Velasco-Muñoz et al., 2021). These strategies can be applied to agricultural production systems to reduce waste generation and identify alternative uses for residual materials. Circular business models further demonstrate that agro-industrial waste can create value through energy recovery, nutrient recycling, and the development of bio-based products (Donner et al., 2020).

Waste-to-energy applications are particularly relevant to rural areas where energy access and waste management remain interconnected development concerns. Agricultural residues and suitable fractions of village solid waste may be converted into refuse-derived fuel (RDF), bio-briquettes, or biogas. Such pathways could contribute to local energy provision while reducing the unmanaged accumulation of organic residues. Research on rural electrification and circular environmental practices highlights the importance of integrating energy technologies with local resource availability and waste-management arrangements (Cuenca-Enrique et al., 2024; Islam et al., 2024). However, these technologies should not be treated as universally applicable solutions. Their feasibility depends on feedstock characteristics, conversion efficiency, logistics, environmental safeguards, and local demand. Accordingly, biomass valorisation in Klamono–Segun should be understood as an opportunity requiring site-specific technical and economic assessment rather than an established source of energy output.

Sago and Agro-Processing Value Addition

Agro-processing provides a complementary pathway for increasing the economic value retained within resource-producing regions. Instead of selling commodities exclusively in raw or minimally processed forms, local processing can create opportunities for product diversification, employment, and stronger market participation. Research on agro-industrial supply chains indicates that processing capacity and market connections are important considerations in developing regional commodity systems (Elida et al., 2021). More broadly, agricultural and food-processing residues can support additional product development through fermentation, extraction, and other processing technologies (Kover et al., 2022).

Sago is especially important in the Papuan context because it functions both as a traditional food resource and as a potential industrial feedstock. Research on sago starch production indicates that biomass residues and wastewater can contribute to energy requirements within appropriately designed processing systems (Bantacut & Indriyani, 2022). In addition, the characterisation of sago tree components from Papua identifies their potential for biomass energy applications (Susanto et al., 2024). Sago starch also has potential applications in biodegradable materials, although product performance and commercial viability require further assessment (Erami et al., 2025). Meanwhile, research on traditional diets among Indigenous peoples in West Papua identifies factors influencing sago consumption, highlighting the importance of understanding food practices and market conditions when designing development interventions (Sidiq et al., 2022).

These findings suggest that sago development should integrate food security, industrial processing, and residue management rather than prioritising energy production alone. Similar value-addition opportunities may be explored for cocoa, oil palm, rubber, and coconut through fermented cocoa products, crumb rubber, copra oil, and other locally appropriate outputs. Integrating processing with circular resource management could enable residues from one activity to become inputs for another. Nevertheless, the appropriate technology and product mix must reflect local production volumes, infrastructure, market access, and community priorities.

One Group One Product, Indigenous Governance, and Regional Development

The One Group One Product (OGOP) scheme provides an organisational basis for concentrating community-based production around selected commodities. In the Klamono–Segun corridor, the scheme can be extended beyond commodity specialisation by linking local producers with processing facilities, residue-management systems, and market opportunities. Such an extension would connect production-level coordination with a broader regional strategy for value creation and resource efficiency.

However, economic development in Indigenous territories also requires institutional arrangements that recognise customary land rights. Land is embedded in social relationships, cultural identity, and customary authority; consequently, decisions about resource use cannot be evaluated solely through production efficiency or expected financial returns. Research on customary land utilisation and Indigenous resource governance emphasises the relevance of local knowledge, institutional recognition, and the protection of Indigenous communities (Azis & Alputila, 2025; Karso, 2025). Integrating these considerations into development planning is essential to prevent economic initiatives from marginalising the communities whose territories support production.

The quadruple-helix approach offers a governance structure involving academia, business, government, and communities. Academia can contribute research and technical training, businesses can provide investment and market access, government can support regulation and infrastructure, and Indigenous communities and customary institutions can participate in decisions concerning land, labour, and benefit distribution. Although quadruple-helix collaboration can strengthen regional sustainability initiatives, its effectiveness depends on how participation and responsibilities are

implemented in practice (Hakeem et al., 2023). Indigenous ecological knowledge also provides a relevant basis for developing resource-management strategies that reflect local environmental conditions and community experience (Sakapaji, 2022).

Research Synthesis and Conceptual Positioning

The reviewed literature establishes complementary foundations for sustainable development in Klamono-Segun: green economy theory provides the overarching development orientation; circular economy principles guide resource recovery; agro-processing supports regional value addition; and Indigenous governance establishes the institutional conditions for legitimate implementation. However, these dimensions must be connected within a framework responsive to the corridor's specific commodity structure, spatial allocation, and customary land context.

This study addresses that integration challenge by combining biomass waste-to-energy, agro-processing, the circular 9R framework, OGOP, and quadruple-helix governance. The resulting framework is intended to guide differentiated development pathways across the seven Development Zone Units while positioning Indigenous customary institutions as active governance partners. Because the analysis relies on secondary planning data and literature-based residue mapping, the framework represents a conceptual planning contribution rather than an empirically validated development model. Its technical feasibility, economic viability, and institutional effectiveness require subsequent field-based assessment.

3. Methodology

Research Design and Study Area

This study employed a descriptive qualitative research design combined with policy-model synthesis to develop a sustainable economic development framework for the Klamono-Segun transmigration corridor in Sorong Regency, Southwest Papua, Indonesia. This design was selected because the research addresses the interrelated dimensions of spatial planning, commodity production, biomass-residue utilisation, and institutional governance. Rather than testing causal relationships or estimating statistically significant effects, the study synthesises secondary spatial and planning information with relevant literature to identify locally appropriate development pathways.

The unit of analysis was the Klamono-Segun transmigration corridor, covering 108,885.63 hectares across seven Development Zone Units (Satuan Kawasan Pengembangan, SKP A-G) and twenty-three villages. The corridor's spatial structure, including the Klamono New Growth Centre (KPB), provided the geographical basis for examining the relationship between existing land allocation, commodity production, potential biomass residues, and opportunities for local economic value creation. Particular attention was given to the implications of development interventions for Orang Asli Papua (OAP) and the customary land institutions associated with Maybrat and Aifat territories.

Data Sources and Collection

The study relied on secondary data from three principal sources. First, spatial and planning information was obtained from the Sorong Regency Spatial Plan and transmigration-area planning documents issued by the Directorate of Transmigration Area Potential Development, Ministry of Villages, Disadvantaged Regions, and Transmigration of the Republic of Indonesia. These sources provided the basis for examining spatial allocation and the planned functions of the corridor.

Second, the analysis used the authors' prior spatial characterisation of commodity profiles and development-zone functions across the seven SKPs. These materials informed the identification of

leading commodities and the potential relationship between local production activities and their associated residual streams.

Third, relevant peer-reviewed literature published between 2020 and 2026 was consulted to identify documented biomass-conversion technologies, circular-economy strategies, agro-processing opportunities, and governance approaches. The literature was identified through a structured search of Scopus-indexed and equivalent internationally indexed journals, consistent with the research focus on biomass waste-to-energy, circular economy, value-added processing, and quadruple-helix governance.

The available research materials were used to establish indicative resource-to-technology relationships rather than to quantify actual residue generation in the study area. In particular, the study did not undertake a site-specific biomass audit. Consequently, the quantities, composition, and seasonal availability of residues in individual SKPs were not empirically measured. This distinction was maintained when interpreting the proposed development pathways.

Analytical Procedures

The analysis proceeded through three interconnected stages, moving from spatial characterisation to commodity-residue mapping and subsequent policy-model synthesis.

Stage 1: Spatial allocation analysis. The corridor's spatial-pattern allocation was examined to establish the distribution of major land-use categories. The analysis focused on plantation zones, convertible production-forest zones, food-crop zones, and other reported spatial categories. Their respective areas and percentage shares were used to identify the dominant land-use structure and assess its implications for commodity production and potential resource recovery. The resulting spatial profile provided the contextual basis for identifying opportunities to generate additional economic value without assuming further conversion of customary forest land.

Stage 2: Commodity-to-residue mapping. The leading commodities associated with each SKP were matched to the biomass residues and waste streams commonly documented for those commodities in the reviewed literature. Examples included empty fruit bunches and palm oil mill effluent from oil palm processing, cocoa pod husks, sago pith and bark, coconut shells and husks, rice and maize residues, and timber offcuts. Village solid waste was also considered where relevant to the development-zone profile. Each indicative residue stream was then linked to potential utilisation pathways, including refuse-derived fuel (RDF), bio-briquettes, biogas, compost, biochar, and selected agro-processing products. This procedure was intended to differentiate development opportunities by SKP rather than apply a uniform intervention throughout the corridor.

Stage 3: Policy-model synthesis. The spatial findings and commodity-residue mapping were integrated with the green economy approach, circular 9R framework, existing One Group One Product (OGOP) scheme, and quadruple-helix governance structure. The synthesis connected two operational pathways: biomass waste-to-energy and agro-processing value addition. These pathways were subsequently organised within a governance framework involving academia, business, government, and OAP communities and customary institutions. The resulting model also incorporated the principle that economic benefits should support continued local processing capacity and the protection of customary land rights, Table 1 summarises the analytical sequence and its principal outputs.

Model Construction and Interpretation

The proposed model was constructed by linking the resource base of each SKP to potential economic activities and the institutional arrangements required for implementation. Biomass-residue utilisation was treated as a potential means of recovering energy and material value, while agro-processing was positioned as a complementary mechanism for retaining more economic value within the corridor. The circular 9R framework provided the resource-efficiency orientation, whereas OGOP offered an existing organisational basis for community-based production. Quadruple-helix governance

connected these activities to research capacity, investment, public infrastructure, and Indigenous participation.

The analytical interpretation also considered customary land rights as an institutional condition rather than an external safeguard. Accordingly, the model was framed as a proposed planning framework whose implementation depends on meaningful participation by customary institutions, locally appropriate benefit-sharing arrangements, and recognition of land tenure.

Table 1. Analytical Framework for Developing the Sustainable Economic Development Model

Analytical stage	Principal input	Analytical procedure	Output
Spatial allocation analysis	Spatial plans and transmigration-area planning documents	Examine land-use categories, areas, and percentage shares	Spatial and land-use profile of the corridor
Commodity-to-residue mapping	SKP commodity profiles and relevant literature	Match leading commodities with documented residues and potential utilisation pathways	Indicative residue and value-addition opportunities for SKP A–G
Policy-model synthesis	Spatial findings, residue mapping, and conceptual frameworks	Integrate waste-to-energy, agro-processing, the 9R framework, OGOP, and quadruple-helix governance	Proposed sustainable economic development framework

Source: Authors' synthesis based on the study's secondary spatial and planning data and reviewed literature.

Analytical Limitations and Validation Requirements

The study's conclusions are limited by its reliance on secondary planning information and literature-derived commodity-to-residue relationships. No field-based waste audit, primary stakeholder interviews, quantitative techno-economic assessment, or empirical model validation was undertaken. Therefore, the proposed technologies and development pathways should be interpreted as indicative opportunities, not as demonstrated outcomes or confirmed investment options.

Further research should establish residue quantities and seasonal availability through field measurements, evaluate technical and financial feasibility, and assess environmental implications at the individual-SKP level. Participatory consultation with OAP communities and customary institutions is also necessary to examine institutional acceptability and the distribution of benefits. These steps would provide the empirical basis for evaluating the proposed framework's feasibility and transferability to other resource-frontier regions in eastern Indonesia.

4. Results

Spatial Allocation and Development Characteristics of the Klamono–Segun Corridor

The spatial allocation of the Klamono–Segun transmigration corridor indicates a strong concentration of land designated for plantation and convertible production-forest activities. As shown in Table 2, plantation zones account for 45.65% of the reported area, while convertible production-forest zones represent 43.98%. Together, these two categories account for 89.63% of the corridor's spatial allocation. By comparison, the food-crop zone covers only 842.63 hectares, equivalent to 0.77% of the reported total.

This spatial structure identifies two relevant characteristics for sustainable regional development. First, the corridor has a substantial land base associated with commercial commodities and production activities. Second, the relatively small allocation for food crops highlights the importance of considering

livelihood diversification and food security alongside commodity-oriented development. The findings establish the spatial context for examining how existing production systems might support additional economic activities without assuming further conversion of customary forest land.

Table 2. Spatial-Pattern Allocation of the Klamono–Segun Transmigration Corridor

Spatial allocation category	Area (ha)	Share (%)
Plantation Zone	49,710.57	45.65
Convertible Production Forest Zone	47,893.00	43.98
Permanent Production Forest Zone	3,666.79	3.37
Water Bodies	2,400.79	2.20
Mangrove Ecosystem Zone	1,933.80	1.78
Nature Tourism Zone	1,479.01	1.36
Food Crop Zone	842.63	0.77
Urban Settlement Zone	711.35	0.65
Other categories (rural settlement, local protection, mixed CPF)	245.69	0.24
Total (as reported)	108,883.63	100.00

Indicative Biomass Residue and Value-Addition Opportunities across the Seven SKPs

The mapping of commodity profiles against residue streams documented in the literature identifies potential resource-recovery and agro-processing pathways across all seven Development Zone Units. Table 3 presents these opportunities by linking each SKP's principal commodities with associated waste streams and possible value-added outputs.

Table 3. Indicative Biomass and Value-Addition Potential by Development Zone Unit

SKP	Lead commodities	Principal biomass/waste stream	Priority value-addition pathway
A	Oil palm, paddy	Empty fruit bunches, palm oil mill effluent (POME), rice husk, urban solid waste	RDF/bio-briquette hub; rice-husk-powered agro-processing centre serving KPB
B	Cocoa, sago	Cocoa pod husks, sago pith and bark	Fermented and dried cocoa beans; sago bio-briquettes and organic packaging
C	Paddy, maize	Rice and maize straw and husks	Compost and biochar for soil restoration; husk-fuelled dryers
D	Coconut, rubber	Coconut shells and husks, rubber wood offcuts	Coconut-shell charcoal briquettes; crumb rubber and copra oil
E	Fisheries, annual crops	Fish and shellfish processing waste	Fish-waste biogas; fishmeal and organic fertiliser
F	Sago, cocoa, vegetables	Sago pith, fibrous residues, vegetable waste	Sago bio-briquettes; starch and bioplastic pilot unit
G	Rattan, timber, honey	Timber and rattan offcuts, forest-garden biomass	Charcoal briquettes and non-timber forest-product processing

The mapping reveals that potential resource-recovery activities are distributed across the corridor rather than restricted to the main growth centre. SKP A is associated with oil palm and paddy residues, providing a potential basis for energy recovery and processing support around KPB. SKPs B and F combine sago-related residues with opportunities for food processing and bio-based products, while SKP D presents potential linkages between coconut and rubber processing. SKPs C, E, and G offer additional pathways involving crop residues, fisheries waste, and forest-product processing.

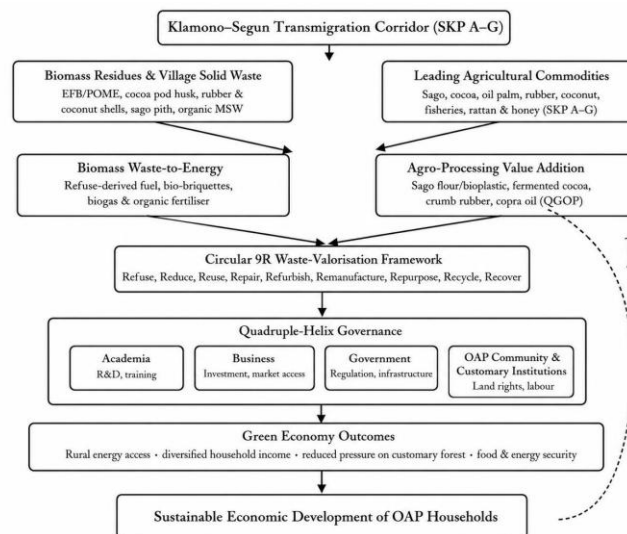
These pathways are indicative rather than quantitatively established. The analysis does not determine annual residue volumes, conversion yields, production costs, or expected revenues for individual SKPs. Their identification therefore provides a basis for prioritising subsequent field assessments rather than confirming the technical or financial feasibility of specific facilities.

Integrated Sustainable Economic Development Framework

The spatial and commodity-residue findings inform the proposed development framework presented in Figure 1. The framework connects two complementary pathways: biomass waste-to-energy and agro-processing value addition. The first focuses on converting suitable agricultural, forestry, and village waste streams into energy or other recoverable products. The second focuses on increasing the value retained from commodities through processing within the corridor.

Both pathways are integrated through the circular 9R framework and the existing One Group One Product (OGOP) scheme. A quadruple-helix governance structure connects academia, business, government, and OAP communities and customary institutions. The framework consequently links resource utilisation and regional value creation with institutional participation and customary land governance. Its implementation, however, remains conditional on site-specific resource assessments, investment feasibility, and meaningful participation by Indigenous customary institutions.

Figure 1. Sustainable Economic Development Model for the Klamono-Segun Transmigration Corridor through a Green Economy Approach



Source: Authors' synthesis

The proposed framework represents the synthesis of the study's spatial analysis, indicative commodity-residue mapping, and governance concepts. It provides a planning structure for further investigation but does not constitute empirical validation of the proposed economic, environmental, or social outcomes.

5. Discussion

Reframing the Existing Land-Use Structure through a Green Economy Approach

The findings demonstrate that the Klamono–Segun corridor's spatial allocation creates both development opportunities and structural constraints. Plantation and convertible production-forest zones account for 89.63% of the reported area, whereas the food-crop zone represents only 0.77%. This concentration reinforces the importance of examining how existing commodity production can generate additional economic value without relying on further land conversion. Rather than interpreting commercial land allocation solely as a source of environmental pressure, the proposed framework considers its associated biomass residues as potential inputs for complementary economic activities.

This interpretation is consistent with green-transition research that emphasises the integration of environmental objectives and regional economic development (Xu et al., 2024). It also extends circular-economy scholarship by linking resource recovery to the spatial and institutional characteristics of a specific transmigration corridor (Donner et al., 2020; Velasco-Muñoz et al., 2021). However, residue utilisation cannot independently resolve the corridor's food-security and land-allocation challenges. The proposed approach should therefore complement, rather than replace, measures addressing livelihood diversification, food production, and customary land protection.

Biomass Valorisation and Regional Value Creation

The commodity-to-residue mapping identifies potential opportunities for connecting waste management with energy recovery and agro-processing across all seven SKPs. Oil palm residues in SKP A, sago residues in SKPs B and F, and coconut and rubber residues in SKP D provide examples of how resource characteristics can inform differentiated development pathways. This approach is consistent with research documenting the potential of oil palm biomass for energy applications and resource recovery (Nabila et al., 2023; Suhartini et al., 2022).

Nevertheless, identifying a suitable residue stream does not establish the feasibility of a particular conversion technology. Feedstock availability, collection distances, moisture content, processing requirements, and market demand may determine whether an intervention is technically and economically viable. Accordingly, the proposed RDF, bio-briquette, and biogas pathways should be treated as candidates for further assessment, not as confirmed energy solutions. This qualification is especially important because the present study uses literature-derived residue relationships rather than measurements from the seven SKPs.

The framework also links biomass utilisation with agro-processing to broaden opportunities for regional value creation. Research on agricultural waste valorisation indicates that residues may support energy recovery and additional product development (Kover et al., 2022). For Klamono–Segun, combining residue management with the processing of sago, cocoa, oil palm, rubber, and coconut could strengthen connections between primary production and downstream economic activities. This integrated perspective is more comprehensive than treating waste-to-energy as an isolated intervention. Its potential contribution to employment, household income, and energy access, however, remains to be assessed empirically.

Sago, Food Security, and Circular Production Systems

The sago-producing SKPs illustrate the importance of balancing industrial opportunities with local food systems. Research has identified the potential of sago biomass for energy utilisation and has examined energy sufficiency within closed-process sago starch production (Bantacut & Indriyani, 2022; Susanto et al., 2024). Meanwhile, research on Indigenous dietary practices in West Papua highlights factors influencing sago consumption (Sidiq et al., 2022). Together, these studies support an approach that considers sago as both a food resource and a potential input for value-added processing.

The implication is that residue valorisation should prioritise processing arrangements that do not undermine the food and livelihood functions of sago. Potential applications in starch production, bio-based materials, and briquettes require separate assessments of feedstock allocation, processing performance, and market viability (Erami et al., 2025). Integrating these considerations within a circular production system could improve resource efficiency while retaining the cultural and livelihood significance of sago. Such benefits remain conditional on appropriate technology selection and community-defined priorities.

Customary Governance as a Condition for Sustainable Development

The proposed quadruple-helix structure positions academia, business, government, and Indigenous communities within a shared governance framework. This approach responds to the recognition that technical efficiency alone cannot guarantee legitimate or sustainable development in territories governed by customary land rights. Research on regional sustainability identifies the potential of quadruple-helix collaboration while highlighting the challenges of translating collaborative principles into practice (Hakeem et al., 2023). Studies of customary land utilisation and Indigenous resource governance further emphasise the relevance of institutional recognition and protection of community interests (Azis & Alputila, 2025; Karso, 2025).

For Klamono–Segun, meaningful participation requires more than consultation. Customary institutions must be involved in decisions concerning land access, project location, benefit distribution, and the use of local resources. Indigenous ecological knowledge can also inform resource-management decisions and strengthen the contextual relevance of development interventions (Sakapaji, 2022). Without these arrangements, projects intended to generate environmental and economic benefits could reproduce existing land-tenure tensions.

The framework's principal contribution is therefore its integration of resource valorisation, regional value creation, and customary governance within a place-specific planning approach. Its effectiveness remains unverified, and further research must establish technical feasibility, financial viability, and institutional acceptability before implementation or replication is recommended.

Policy Implications and Recommendations

The proposed framework has three policy implications for sustainable development in the Klamono–Segun corridor. First, the Sorong Regency government and relevant national agencies should commission a site-specific biomass audit across the seven SKPs. Measurements of residue volumes, seasonal availability, collection requirements, and feedstock characteristics should precede investment in RDF, bio-briquette, or biogas facilities. Second, pilot initiatives should be prioritised according to verified resource availability, infrastructure, market access, and processing requirements. SKP A could be assessed for oil palm residue utilisation, while SKP F could be examined for integrated sago processing and residue recovery. These locations should remain provisional priorities until technical and financial feasibility is established.

Third, customary land governance must be incorporated into project design from the outset. Participatory agreements with Maybrat and Aifat customary institutions should address land access, decision-making authority, employment, and benefit-sharing. Government agencies should also establish monitoring indicators covering resource efficiency, local value creation, environmental performance, and community participation.

Implementation should proceed through staged assessment, pilot testing, and independent evaluation rather than immediate corridor-wide replication. Future research should combine techno-economic analysis with household-level and institutional assessment to determine whether the

proposed interventions improve livelihoods and energy access without compromising customary rights or food security.

6. Conclusion

This study develops an integrated green economy framework for sustainable economic development in Indigenous Papuan transmigration areas, using the Klamono-Segun corridor in Southwest Papua, Indonesia, as a case study. The analysis indicates that the corridor's existing land-use structure and diverse local commodities provide a basis for exploring more resource-efficient and locally oriented development pathways. However, translating these resources into inclusive economic benefits requires a shift from commodity production alone toward integrated resource utilisation, value addition, and participatory governance.

The proposed framework connects two complementary pathways: biomass residue valorisation for renewable energy and the development of agro-processing activities to increase the value of local commodities, including sago, cocoa, oil palm, rubber, and coconut. Integrating these pathways with the circular economy's 9R principles and the One Group One Product scheme offers a conceptual approach to reducing resource losses, strengthening local production systems, and expanding opportunities for community-based enterprises. The framework further emphasises that collaboration among government, academia, businesses, and Indigenous communities is essential, particularly where customary land rights and local decision-making shape development outcomes.

The study's principal contribution is the conceptual integration of circular bioeconomy strategies, regional value creation, and Indigenous customary governance within a transmigration development context. Nevertheless, the proposed framework remains indicative rather than empirically validated. Its practical applicability cannot be established without site-specific biomass inventories, techno-economic feasibility assessments, market analysis, and meaningful engagement with customary institutions. Future research should evaluate the availability and seasonal characteristics of biomass residues, the viability of proposed processing technologies, and the distribution of economic and social benefits. Such evidence is necessary to determine whether the framework can support sustainable livelihoods, resource efficiency, and inclusive regional development while safeguarding customary rights and local food security.

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