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# Integrating Sustainability and Inclusion in Agricultural Value Chains: A Multi-Criteria Investment Framework for Nigeria

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**Abstract: This study develops and applies a Multi-Criteria Decision Analysis (MCDA) framework integrated with Multi-Objective Linear Programming (MOLP) to optimize agricultural investment allocation across seven value chains within Nigeria's LIFE-ND (Livelihood Improvement Family Enterprises–Niger Delta) program. Traditional mono-objective investment models often emphasize economic return, marginalizing socially significant sectors such as nutrition, marketing, and fishery. By incorporating economic efficiency, equity, and sustainability into the model anchored on the Triple Bottom Line (TBL) framework the research introduces a composite performance approach to evaluate sectoral contributions. Results revealed a dominant allocation to crop production, while sectors like fish and nutrition remain underfunded despite demonstrating high responsiveness in elasticity analysis. Sensitivity and threshold evaluations reveal the model's heavy reliance on crop-sector performance, raising concerns about resilience and diversification. The findings underscore the need for inclusive, impact-driven investment policies that align with national and international development goals, including the Sustainable Development Goals (SDGs). The study offers a replicable framework for evidence-based resource allocation, ensuring balanced growth, social inclusion, and sustainable agri food systems in sub-Saharan Africa.**

***Keywords**: Multi-Criteria Decision Analysis, Agricultural Investment, Value Chain Optimization, Sustainability, Triple Bottom Line, Equity, Life-ND Program.*

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## I. INTRODUCTION

Nigeria's agricultural sector is central to its economic growth, rural employment, and food security ambitions. However, resource allocation within value chains often prioritises economic returns at the expense of inclusion, equity, and environmental sustainability. Traditional investment strategies, typically mono-objective and profit-centred, tend to favour capital-intensive and high-yield sectors such as crop production, often underfunding equally important but less economically dominant areas like nutrition, fishery, and agribusiness marketing (Moluno & Eme, 2025). This imbalance has led to systemic inefficiencies and missed opportunities for inclusive development.

Against this backdrop, the Livelihood Improvement Family Enterprises in the Niger Delta (LIFE-ND) initiative seeks to strengthen agribusiness ecosystems through coordinated investments across seven value-chain enterprises. Yet, optimizing these allocations requires more than economic efficiency alone. As Guo et al. (2020) and Philip & Suresh (2024) argue, modern agri-food systems must simultaneously enhance productivity, foster environmental resilience, and ensure social inclusion especially for youth, women, and rural populations. Despite global progress in multi-criteria agricultural modelling, significant gaps persist in integrating inclusive, impact-driven metrics into resource optimization frameworks, particularly in sub-Saharan Africa. Most existing models do not fully account for the trade-offs between efficiency, equity, and sustainability in localized contexts (Popova & Adamenko, 2022; Vostriakova et al., 2021). This study fills that gap by introducing a Multi-Objective Linear Programming (MOLP) model that balances economic, social, and environmental goals. The model addresses the pressing need for evidence-based, policy-aligned investment tools that promote broad-based development within Nigeria's agribusiness value chains (World Bank, 2021; IFAD, 2020).

The reviewed studies emphasize a global shift toward inclusive, sustainable, and technology-driven agricultural systems. The study by Guo et al. (2020) proposed an integrated systems model to optimize food-bioenergy-resource linkages in the Global South. Philip and Suresh

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(2024) highlighted the need for massive investment in agricultural finance and insurance to meet growing food demands. Vostriakova et al. (2021) stressed the role of LEAN logistics and simulation in reducing food waste. Popova and Adamenko (2022) advocated transitioning to inclusive innovation systems under Agriculture 4.0 to bridge access gaps. Tulush and Radchenko (2022) analyzed agricultural resilience during the crisis in Ukraine, calling for reform in fiscal and regulatory support. Erokhin et al. (2020) identified trade and competitive advantages in Central Asia, proposing regional collaboration. Jiang et al. (2024) addressed carbon emissions and proposed a traceable, equitable supply chain using pricing models and risk analysis tools like Analytic Hierarchy Process (AHP) and fuzzy evaluation. Qorri and Felföldi (2024) noted gaps in understanding financial failures in agricultural cooperatives, despite their growth. Asteraye et al. (2024) revealed the significant but underrecognized economic role of equids in Ethiopia. Moluno and Eme (2025) applied Data Envelopment Analysis and Tobit regression to assess technical efficiency across key Nigerian crops, emphasizing the need for cost control and targeted interventions. Collectively, these works underscore the importance of multidimensional strategies economic, environmental, and social for optimizing agricultural systems, supporting the need for multi-criteria frameworks in contexts like Nigeria's LIFE-ND program.

➢ *Conceptual and Theoretical Framework*

This study is anchored on two interlinked theoretical constructs: Multi-Criteria Decision Analysis (MCDA) and the Triple Bottom Line (TBL) sustainability framework.

- *Multi-Criteria Decision Analysis (Mcda)*

MCDA provides a structured decision-making approach when multiple, often conflicting objectives must be considered (Mavrotas, 2009). In agriculture, MCDA has been increasingly used to reconcile economic efficiency with broader goals such as environmental stewardship and social equity (Keeney & Raiffa, 1993; Mendoza & Martins, 2006). The current study applies a Weighted Sum Model (WSM) a sub-type of MCDA which allows the combination of multiple indicators into a composite score used in optimization routines. This technique is especially useful in policy contexts where competing goals (e.g., profitability vs. equity) must be balanced transparently and systematically (Triantaphyllou & Sánchez, 1997).

- *Triple Bottom Line* (*TBL*) *Sustainability Framework*

First conceptualized by Elkington (1997), the TBL framework integrates economic, social, and environmental dimensions into strategic planning and evaluation. In agriculture, the TBL ensures that productivity gains do not undermine equity or ecosystem integrity. For this study, the TBL serves as the normative anchor for identifying and weighting the seven investment objectives: Economic Efficiency, Federal and State Redistribution, Social Wellbeing, Environmental Improvement, Gender Equity, and Youth Employment.

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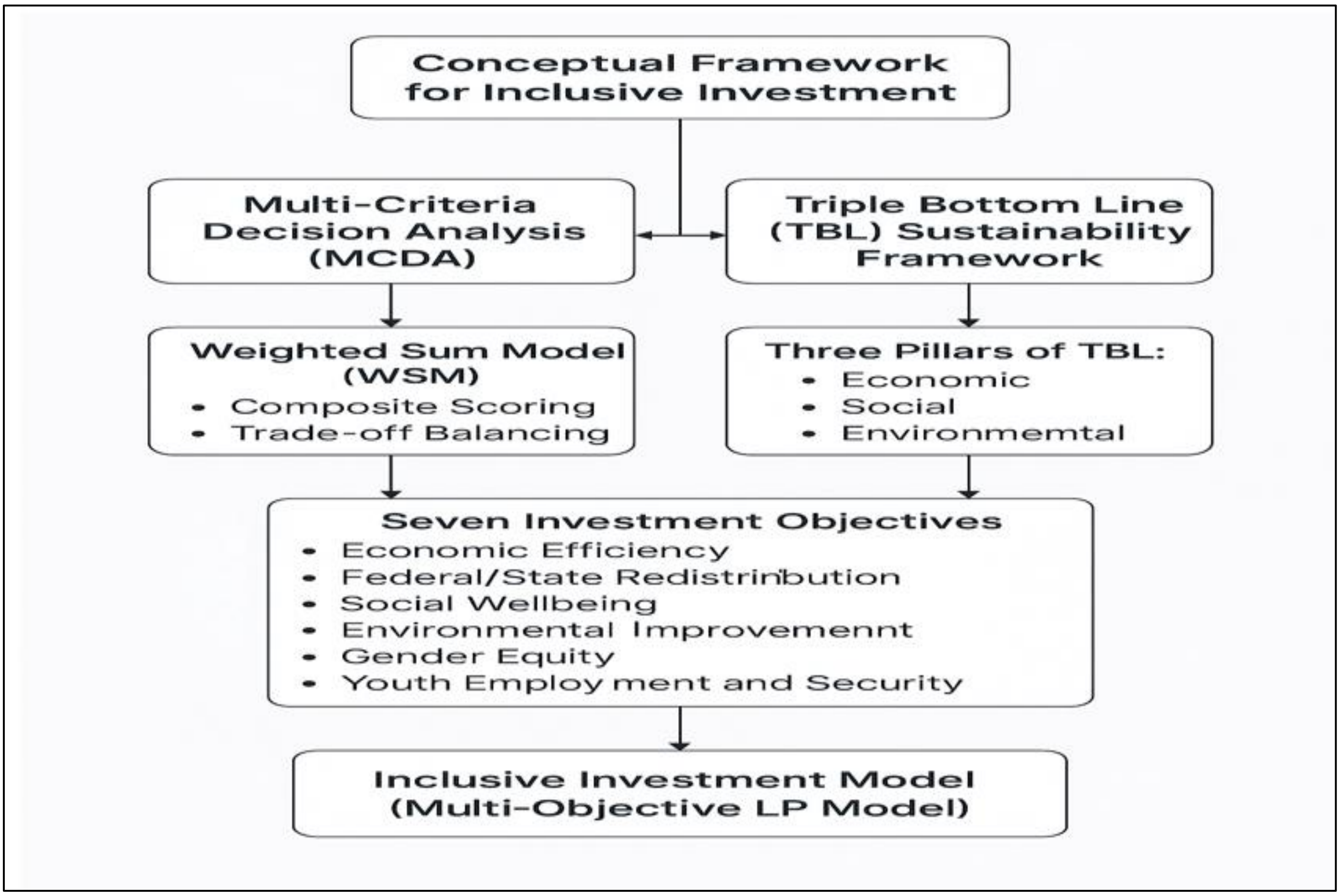


Fig 1 Flowchart for Multi-Criteria Agricultural Investment Optimization

The flow chart presented in Figure 1 shows that the MCDA (Multi-Criteria Decision Analysis) introduces the Weighted Sum Model to handle trade-offs among multiple conflicting objectives. While the Triple Bottom Line (TBL) ensures investments balance economic, social, and environmental goals. The seven investment objectives are derived from both frameworks and are evaluated collectively. Hence, this leads to a Multi-Objective Linear Programming (LP) model that promotes inclusive and impact-driven resource allocation. This conceptual-theoretical synthesis enables a dynamic and inclusive investment planning model one that maximizes systemic benefit while minimizing social exclusion or sectoral neglect.

Hence, the motivation behind this study stems from the persistent imbalance in agricultural investment allocation in Nigeria, where economically dominant sectors like crop production receive disproportionate attention, often to the detriment of socially critical but less profitable sectors such as nutrition, fishery, and marketing. This inequity undermines inclusive development, gender equity, and environmental sustainability, particularly in programs like the Livelihood Improvement Family Enterprises in the Niger Delta (LIFE-ND) initiative. The objective of the study is to develop an evidence-based framework for optimizing investment distribution across seven agribusiness value chains by integrating economic, social, and environmental indicators into a unified decision-making tool. To achieve this, the study adopts a Multi-Objective Linear Programming (MOLP) model grounded in Multi-Criteria Decision Analysis (MCDA) and the Triple Bottom Line (TBL) framework, aiming to balance profitability with broader development goals. By embedding sensitivity, threshold, and elasticity analyses into the model, the research enables policymakers to make transparent, equitable, and impact-driven investment decisions. In summary, the study is motivated by the need to support systemic transformation in agricultural planning, one that aligns with global sustainability frameworks (e.g., SDGs) and ensures the inclusion of underrepresented stakeholders such as women, youth, and smallholder farmers.

## II. RESEARCH METHODOLOGY

This study adopts a quantitative framework to evaluate and optimize investment allocations across seven agribusiness value chains under the LIFE-ND program. By integrating composite performance indicators spanning economic, social, and environmental dimensions into a multi-objective decision model, the research aims to identify evidence-based, equitable allocation strategies. Methodologically, the study applies linear programming, sensitivity testing, elasticity analysis, and threshold modelling to ensure robustness, transparency, and responsiveness in agribusiness policy planning, consistent with best practices in development economics and operational research.

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### A. *Source of Data Collection*

The data utilized for evaluating economic efficiency across the seven LIFE-ND agribusiness value chain enterprises poultry, crop, fish, nutrition, retail and wholesale, agricultural fabrication, and marketing were obtained through a multi-tiered institutional framework involving both national and sub-national stakeholders. Key sources included administrative and financial records from the National Project Coordinating Office (NPCO) in Port Harcourt, particularly from the Agribusiness Promotion and Monitoring & Evaluation Coordinators. Supplementary data were gathered from State Agribusiness Promotion Officers and State M&E Units in the nine participating Niger Delta states, complemented by inputs from local beneficiary communities and agribusiness clusters. These data encompassed operational costs, projected revenues, and infrastructural investments (e.g., roads, boreholes, culverts), aligning with project documentation and implementation guidelines such as the LIFE-ND Grant and Subsidy Manual and the LIFE-ND Implementation Framework (IFAD, 2020). Additionally, national-level data were retrieved from the Federal Ministry of Agriculture and Rural Development, Abuja, ensuring consistency with national agricultural planning benchmarks. This multi-source approach adheres to best practices in development evaluation, where triangulated data enhances the validity of project assessments (OECD, 2010; IFAD, 2020).

### B. *Method of Data Analysis*

➢ *Model Structure*

- *Decision Variables*

Let the decision variables represent the proportion of total investment allocated to each agribusiness enterprise:

- ✓ $x_1$: Poultry Production and Processing
- ✓ $x_2$ : Crop Production and Processing
- ✓ $x_3$ : Fish Production and Processing
- ✓ $x_4$: Nutrition Production and Processing
- ✓ $x_5$: Retail and Wholesale Enterprise
- ✓ $x_6$ : Agricultural Fabrication
- ✓ $x_7$ : Marketing Enterprise

All decision variables are continuous and bounded between 0 and 1.

- *Objective Function*

To achieve a reasonable investment policy, a weighted sum method common in multi-criteria decision analysis is applied (Mavrotas, 2009). Each sector's contribution is evaluated across seven performance criteria:

- ✓ Economic Efficiency
- ✓ Federal Economic Redistribution
- ✓ State Economic Redistribution
- ✓ Social Wellbeing
- ✓ Environmental Improvement
- ✓ Gender Equality
- ✓ Youth Employment and Securit

Table 1 Net Benefits of LIFE-ND Agribusiness Multi-Purpose and Multi-Objective

| **Enterprises** | **Objectives** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Economic Efficiency** | **Federal Econ. Redistr.** | **State Econ. Redistr.** | **Social Wellbeing** | **Environmental Improvement** | **Gender Equality** | **Youth Employment and security** |
| Poultry prod. &process. | 15.10 | 14.15 | 14.15 | 12.27 | 12.27 | 13.2 | 13.21 |
| Crop prod. & process. | 22.86 | 21.43 | 21.43 | 18.48 | 18.48 | 19.9 | 19.9 |
| Fish prod. & process. | 0.50 | 0.47 | 0.47 | 0.41 | 0.41 | 0.44 | 0.44 |
| Nutrition prod.& processing | 0.50 | 0.47 | 0.47 | 0.41 | 0.41 | 0.44 | 0.44 |
| Retail & Wholesale | 1.64 | 1.54 | 1.54 | 1.34 | 1.34 | 1.44 | 1.44 |
| Fabrication | 2.36 | 2.21 | 2.21 | 1.92 | 1.92 | 2.07 | 2.07 |
| Marketing | 0.24 | 0.22 | 0.22 | 0.19 | 0.19 | 0.21 | 0.21 |

Source: Authors Computation (2024

The 1 shows the net benefit in billions of Naira of the multi-purpose and multi-objectives. This table is determines the best multi-purpose project among others that can be further developed for optimum system benefits. The foregoing is achieved by the products of the empirical prior distribution and the payoff values. Consequently, the multipurpose that has the Maximum Expected Monetary Value (EMV*) will be selected as a project worth investing on for the benefit of the incubates, incubators, the region and the country at large.

Based on Table 1, a composite performance score $S_i$ is computed as the mean score of each enterprise across these objectives.

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Table 2 The Resulting Composite Scores are:

| **Sector** | **Composite Score ($S_i$)** |
|---|---|
| Poultry | 13.48 |
| Crop | 20.50 |
| Fish | 0.45 |
| Nutrition | 0.45 |
| Retail & Wholesale | 1.47 |
| Fabrication | 2.12 |
| Marketing | 0.21 |

Thus, the objective function can be formulated as:
Maximize:

$$Z = 13.48x_1 + 20.50x_2 + 0.45x_3 + 0.45x_4 + 1.47x_5 + 2.12x_6 + 0.21x_7 \quad (1)$$

- *Subject to the following constraints*

To ensure equity and representation of all enterprises, the following constraints are imposed:

- ✓ Total Allocation Constraint:

$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 = 1 \quad (2)$$

- ✓ Minimum Allocation Constraint:

$$x_i \geq 0.05, for\ all\ i = 1,\dots,7 \quad (3)$$

These constraints ensure that each sector receives at least 5% of the total investment, aligning with inclusive growth goals and ensuring systemic participation (World Bank, 2021). This formulated multi-objective model aligns with national and international development frameworks such as Nigeria's Agricultural Promotion Policy and the Sustainable Development Goals. By integrating economic and social indicators, the model supports evidence-based, equitable investment decision-making across agribusiness value chains. The model ensures balanced support for both high-yield and socially critical enterprises, enhancing regional economic diversification, youth employment, and gender equality.

- *Sensitivity Analysis Framework*

To evaluate the robustness and responsiveness of the optimization model to parameter changes, a sensitivity analysis was conducted on the sector with the highest composite performance score the Crop Production and Processing enterprise. Sensitivity analysis is a well-established technique in optimization and decision science, used to test how the variation in input parameters influences the optimal solution of a model (Saltelli et al., 2008; Pannell, 1997).

When sectors are assigned dominant weights within a multi-objective optimization framework, the resulting model can become highly sensitive to those weights, potentially introducing systemic skewness in resource allocation. This can lead to disproportionate prioritization, reduced policy flexibility, and inefficient diversification, particularly if the model is not stress-tested through sensitivity or scenario analysis. As emphasized by Keeney and Raiffa (1993), without accounting for uncertainties or variability in objective weights, decision models risk entrenching biases that may not align with dynamic developmental goals or equity principles.

The base optimization model, defined as equation (1) was solved under three Crop score scenarios:

- ✓ $Baseline: S_{Crop} = 20.5$
- ✓ $+10\%\ Scenario: S_{Crop} = 22.55$
- ✓ $-10\%\ Scenario: S_{Crop} = 18.45$

All other sector scores remained constant during each simulation to isolate the impact of crop score changes on system-wide allocation dynamics.

The model was implemented using linear programming techniques in *R console*, employing the *lpSolve* package for optimization and ggplot2 for visualization.

- *Threshold Sensitivity Analysis*

To assess the optimization framework's robustness to variations in composite performance scores, a Threshold Sensitivity Analysis was conducted. This technique involves systematically varying the composite score of the dominant sector, in the present study, the Crop Production and Processing sector while holding the scores of all other sectors constant. The goal is to identify the threshold point at which the allocation to another sector (e.g., Poultry) surpasses that of the Crop sector under the optimization model.

This approach is grounded in the principles of parametric sensitivity analysis, where input parameters are perturbed to evaluate their effect on the optimal solution (Saltelli et al., 2008). Specifically, the composite score of the Crop sector was reduced incrementally in 1% steps from its baseline value, and at each step, the optimization problem was resolved using the simplex method under linear programming constraints (Winston & Goldberg, 2004). The constraint ensures that all sectors receive a minimum allocation and the full budget is exhausted.

This analysis provides critical insight into the tipping point of dominance, which has policy implications for maintaining balance and preventing resource concentration. Such threshold-based evaluations are particularly relevant in development investment models, where over-reliance on high-scoring sectors can lead to vulnerability in the face of market, climatic, or institutional shocks (Triantaphyllou & Sánchez, 1997; Keeney & Raiffa, 1993). This methodological step is expected to strengthen the decision-making resilience of the model by identifying the stability margins for sectoral

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scores and informing the design of equitable allocation policies.

- *Elasticity Analysis of Sectoral Allocations*

In this study, an elasticity analysis was carried out to quantify the responsiveness of sectoral allocations to marginal changes in composite performance scores. Elasticity, in the context of multi-objective optimization, refers to the percentage change in a decision variable (optimal allocation) resulting from a 1% change in the corresponding composite score, holding other parameters constant (Charnes et al., 1994; Winston & Goldberg, 2004).

The analysis involved the following steps:

- ✓ Baseline Solution: The original linear programming (LP) optimization model was solved using the composite scores from the seven LIFE-ND agribusiness sectors. The solution yielded a vector of optimal allocations $x = (x_1, x_2, \ldots, x_7)$.
- ✓ Score Perturbation: For each sector iii, its composite score $S_i$ was increased by 1%, yielding a perturbed score $S_i'$, while the scores for the other sectors remained unchanged.
- ✓ Re-optimization: The model was re-optimized using the perturbed scores, and the new allocation $x_i'$ for each sector was computed.
- ✓ Elasticity Computation: The elasticity $E_i$ for each sector was calculated using the standard elasticity formula:

$$E_i = \frac{\%\ \text{change in}\ x_i}{\%\ \text{change in}\ S_i} \quad (4)$$

Sectors with elasticity close to 1 indicate a proportional response, where a 1% score increase leads to a roughly 1% increase in allocation. Elasticities less than 1 reflect allocation inertia, where large score changes are needed to effect noticeable allocation adjustments. Conversely, sectors with elasticity greater than 1 exhibit high sensitivity, making them ideal candidates for strategic policy interventions.

This method allows policymakers to distinguish between robust sectors (with low elasticity) and responsive sectors (with high elasticity), facilitating targeted investments aimed at enhancing sectoral participation and balancing performance distribution across the agribusiness ecosystem (Saltelli et al., 2008; Triantaphyllou & Sánchez, 1997).

The methodology offers a replicable framework for multi-criteria investment decision-making in agricultural development. The combined use of optimization, sensitivity, and elasticity analyses ensures a nuanced understanding of sectoral dynamics and investment trade-offs. This approach not only identifies the most impactful sectors but also highlights allocation thresholds and responsiveness, offering valuable insights for policymakers seeking to balance equity and efficiency. The model's alignment with global frameworks such as the SDGs enhances its relevance for guiding sustainable, inclusive, and data-driven rural development strategie.

# III. RESULTS

Table 3 Sector-Wise Composite Scores, Optimal Allocations, and Contributions to Overall Objective Function Z

| Sector | Composite Score (Si) | Optimal Allocation |
|---|---|---|
| Poultry | 13.48 | 0.05 |
| Crop | 20.5 | 0.7 |
| Fish | 0.45 | 0.05 |
| Nutrition | 0.45 | 0.05 |
| Retail | 1.47 | 0.05 |
| Fabrication | 2.12 | 0.05 |
| Marketing | 0.21 | 0.05 |

Table 3 presents a multi-objective optimization output where each sector's composite performance score (Si) is multiplied by its respective optimal allocation (xi) to derive its contribution to the overall objective function Z. The results show that Crop Production contributes the most significantly to the system (9.23), followed by Poultry Production (3.37), together accounting for the overwhelming majority of the system-wide performance. Other sectors, such as Fish, Nutrition, Retail, Fabrication, and Marketing, contribute minimally, indicating either limited efficiency or lower return potential in the current optimization model

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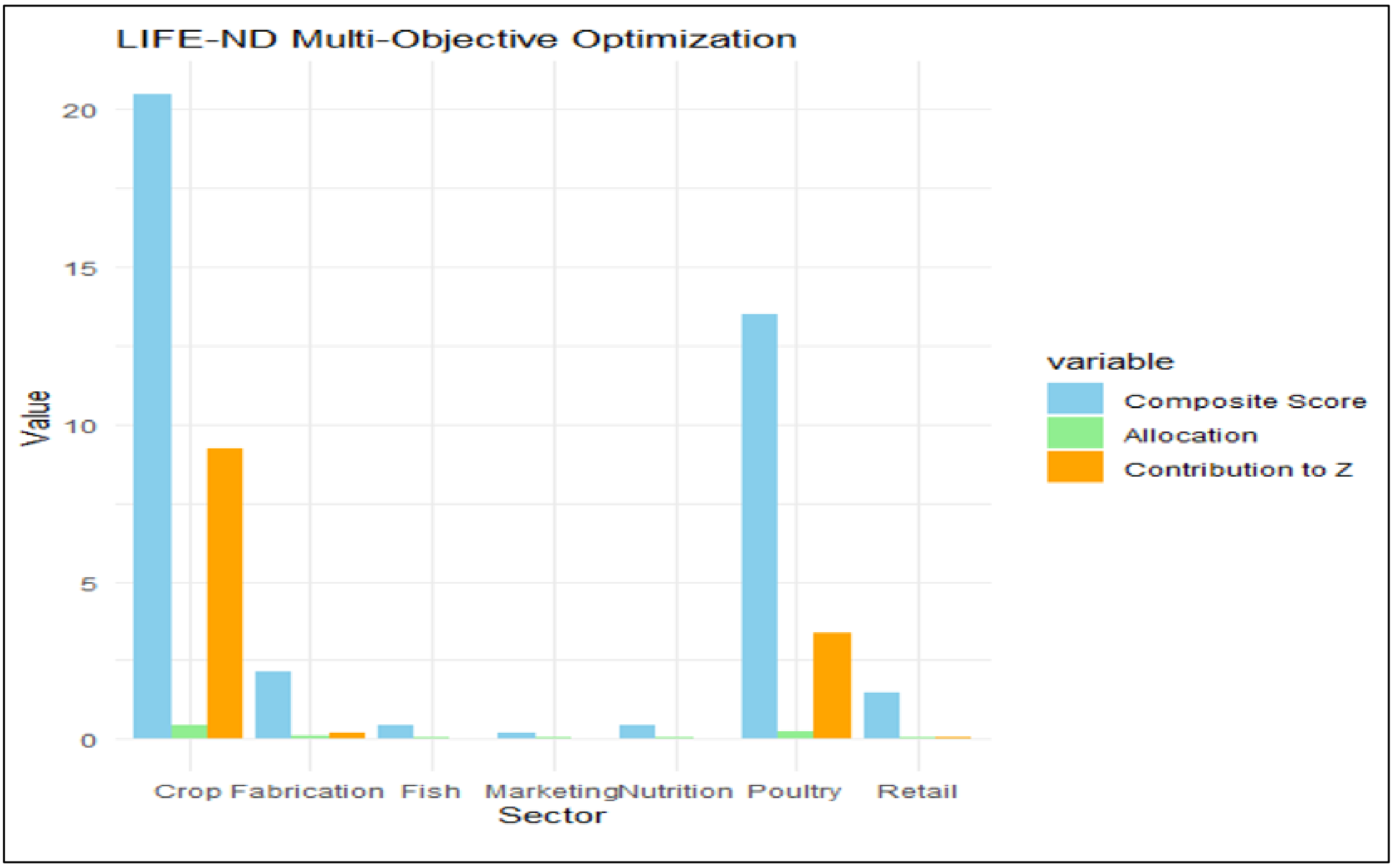


Fig 2 Comparative Visualization of Composite Scores, Optimal Allocations, and Sector Contributions to System Objective (Z) In LIFE-ND Program

The bar chart in Figure 2 visualizes the LIFE-ND Multi-Objective Optimization outcomes by comparing each sector's Composite Score (efficiency and potential impact), Optimal Allocation (xi), and their Contribution to the overall objective function Z. Notably, the Crop sector dominates with the highest composite score and contribution to Z, reflecting its strategic priority for maximizing impact under the optimization model. The Poultry sector follows in importance, contributing significantly to Z due to both a high composite score and allocation. Sectors such as Fish, Nutrition, Marketing, Retail, and Fabrication show marginal contributions, despite receiving small allocations, suggesting either lower efficiency or secondary importance. This implies that strategic resource allocation in the LIFE-ND program should focus more heavily on high-impact sectors like Crop and Poultry while maintaining minimal support for others to foster inclusivity, diversification, and resilience across value chains.

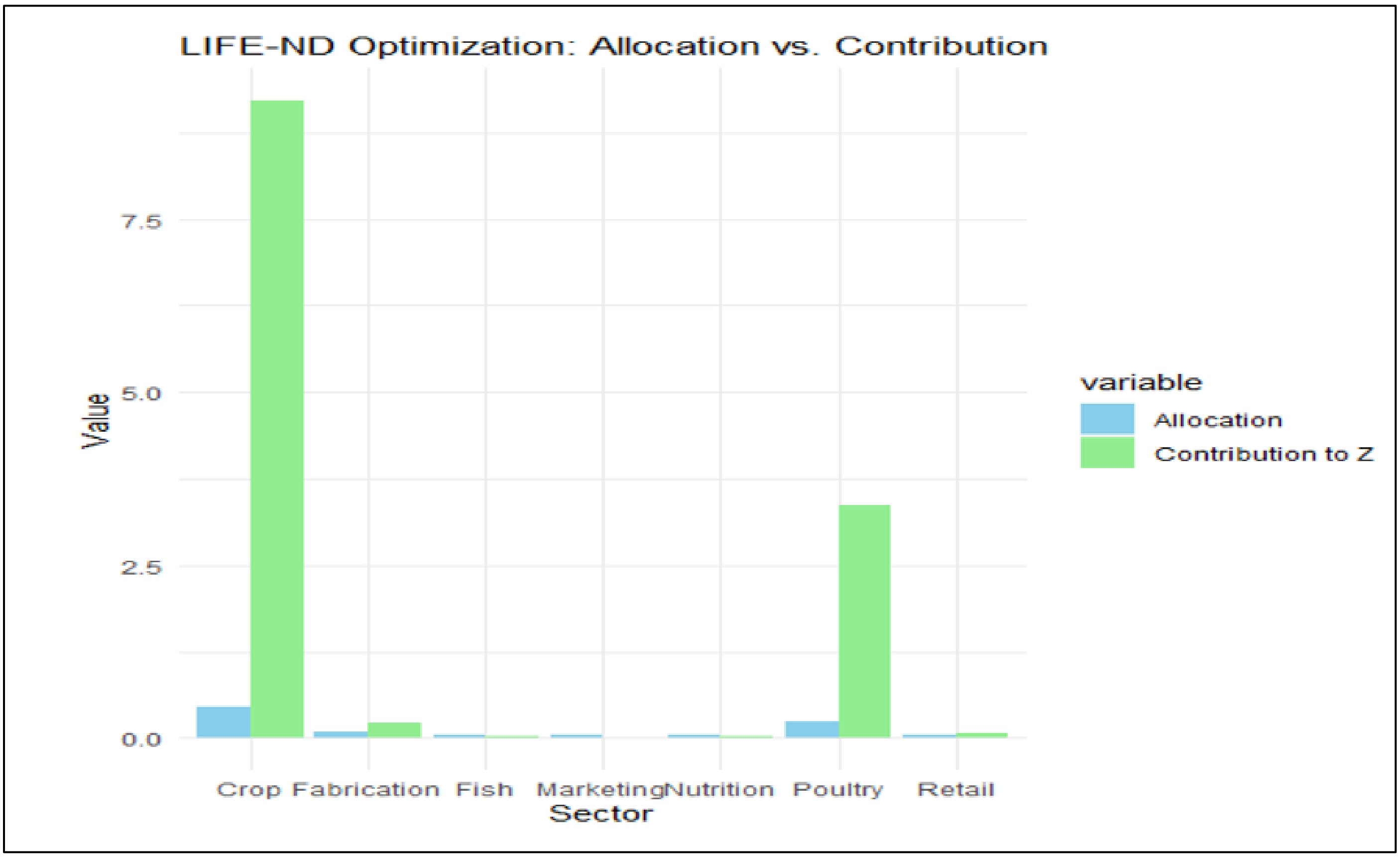


Fig 3 Comparative Analysis of Sector Allocations and Contributions to Objective Function Z in LIFE-ND Multi-Objective Optimization

The result in Figure 3 compares the optimal resource allocations to each sector against their respective contributions to the overall objective value Z. The Crop sector stands out with both the highest allocation and a substantial contribution to Z, reinforcing its central role in achieving maximum economic and developmental efficiency. Poultry, though receiving a smaller share of the allocation, also makes a notable contribution, indicating a high return on investment per unit of allocation. In contrast, sectors like Fish, Nutrition, Marketing, and Retail exhibit both low allocations and minimal contributions to Z, suggesting that, under current parameters, they are less efficient or impactful. The figure emphasizes the importance of evidence-based allocation strategies that prioritize sectors with both high composite scores and potential for system-wide benefit, while still preserving minimal engagement across others for diversity, inclusion, and broader development goals.

Table 4 Sensitivity Analysis of 10% Increase in Crop Sector Score on Allocation and Sectoral Contributions in LIFE-ND Optimization Model

| Sector | Score | Allocation | Contribution |
|---|---|---|---|
| Poultry | 13.48 | 0.05 | 0.6740 |
| Crop | 22.55 | 0.7 | 15.7850 |
| Fish | 0.45 | 0.05 | 0.0225 |
| Nutrition | 0.45 | 0.05 | 0.0225 |
| Retail | 1.47 | 0.05 | 0.0735 |
| Fabrication | 2.12 | 0.05 | 0.1060 |
| Marketing | 0.21 | 0.05 | 0.0105 |

The result in Table 4 demonstrates the impact of increasing the crop sector's composite score by 10% (from 20.5 to 22.55) on the overall allocation and contribution to the objective function. As seen, this adjustment results in the crop sector receiving the highest allocation (0.70) and contributing 15.785 to the objective function, a significant dominance over other sectors. All other sectors, including poultry (previously a major contributor), were assigned minimal allocations of 0.05, leading to drastically lower contributions. This outcome highlights the sensitivity of the optimization model to variations in sectoral scores: even a modest increase in one sector's score can substantially skew resource distribution. Moreover, it suggests that if equity or diversification of investment is desired, constraints or multi-criteria balancing mechanisms must be introduced.

Table 5 Sensitivity Analysis of 10% Decrease in Crop Sector Score on Allocation and Sectoral Contributions in LIFE-ND Optimization Model

| Sector | Score | Allocation | Contribution |
|---|---|---|---|
| Poultry | 13.48 | 0.05 | 0.6740 |
| Crop | 18.45 | 0.7 | 12.9150 |
| Fish | 0.45 | 0.05 | 0.0225 |
| Nutrition | 0.45 | 0.05 | 0.0225 |
| Retail | 1.47 | 0.05 | 0.0735 |
| Fabrication | 2.12 | 0.05 | 0.1060 |
| Marketing | 0.21 | 0.05 | 0.0105 |
| | | | |

The result in Table 5 shows the effect of reducing the composite score of the crop sector from 20.5 to 18.45 (a 10% drop) on allocation and contribution within the LIFE-ND optimization model. Despite the score reduction, the crop sector retains the highest allocation of 0.70 and contributes 12.915 to the objective function. Other sectors remain fixed at minimal allocations (0.05) and low contributions. This suggests that even with a notable decline in its score, the crop sector still dominates the optimization outcome indicating a high level of robustness or model dependence on this sector. The implication is that score weighting heavily dictates optimal outcomes, and without balancing mechanisms, the model risks overly prioritizing a single sector at the expense of diversification or equity in resource distribution.

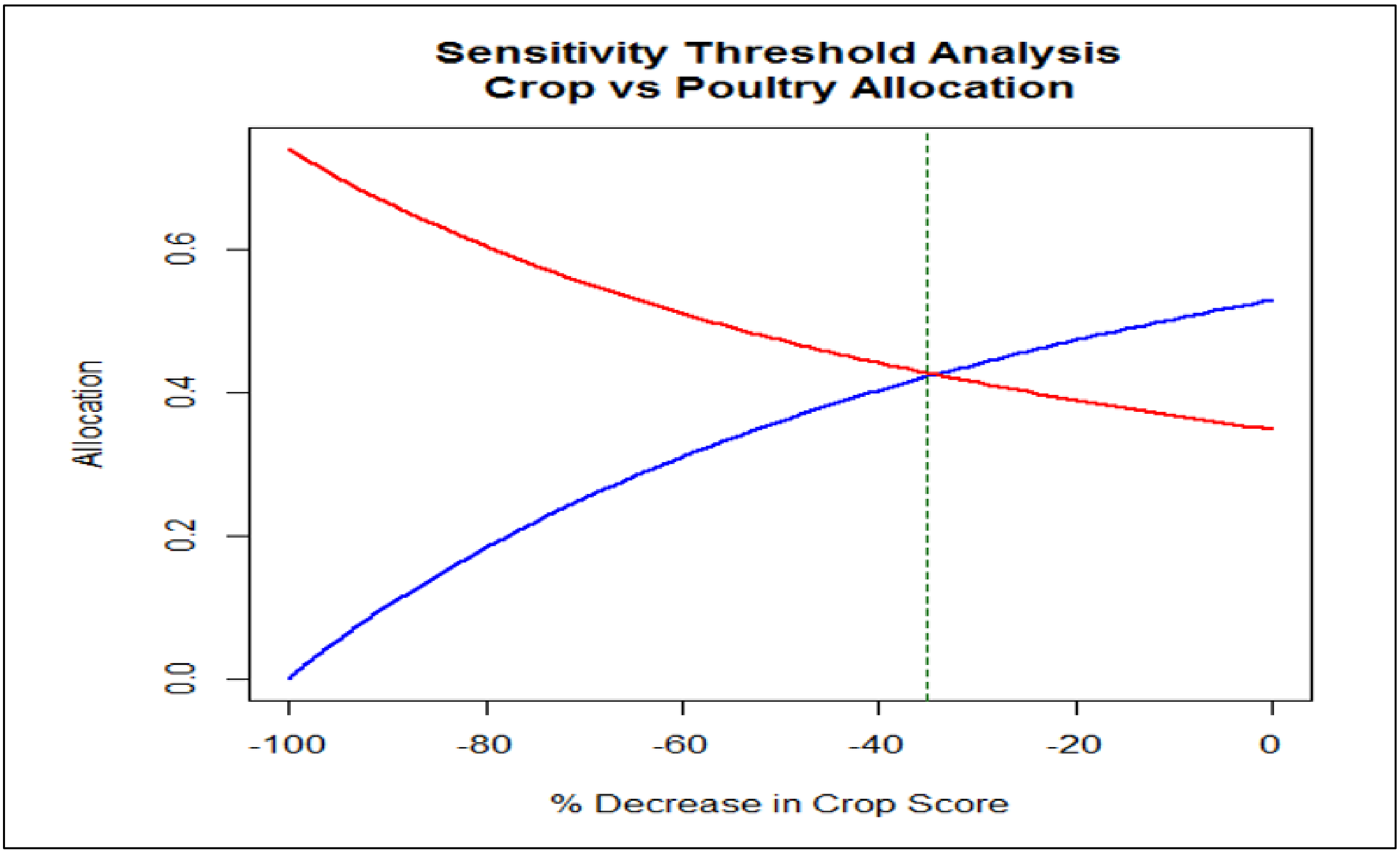


Fig 4 Sensitivity Threshold Analysis of Optimal Allocation: Crop vs. Poultry in LIFE-ND Framework

The plot in Figure 4 illustrates the result of a Sensitivity Threshold Analysis comparing the optimal allocation between the Crop and Poultry sectors in the LIFE-ND multi-objective framework. As the composite score for the Crop sector decreases, its corresponding allocation declines steadily (red line), while the allocation to Poultry increases (blue line). The vertical green dashed line marks the threshold point, approximately at a 38% decrease in Crop's score, beyond which Poultry overtakes Crop in receiving a higher allocation. This demonstrates that the optimization model is highly sensitive to the Crop score small changes around this threshold can result in a reallocation of resources favoring other sectors like Poultry. This insight is critical for planners: while the Crop sector currently dominates due to its high composite score, any significant policy or performance degradation (e.g., lower productivity, market failure) could shift priorities within the system, prompting reallocation. Therefore, maintaining performance in the Crop sector is essential to sustain its dominant role, and alternative sectors should be monitored and supported as they become more competitive.

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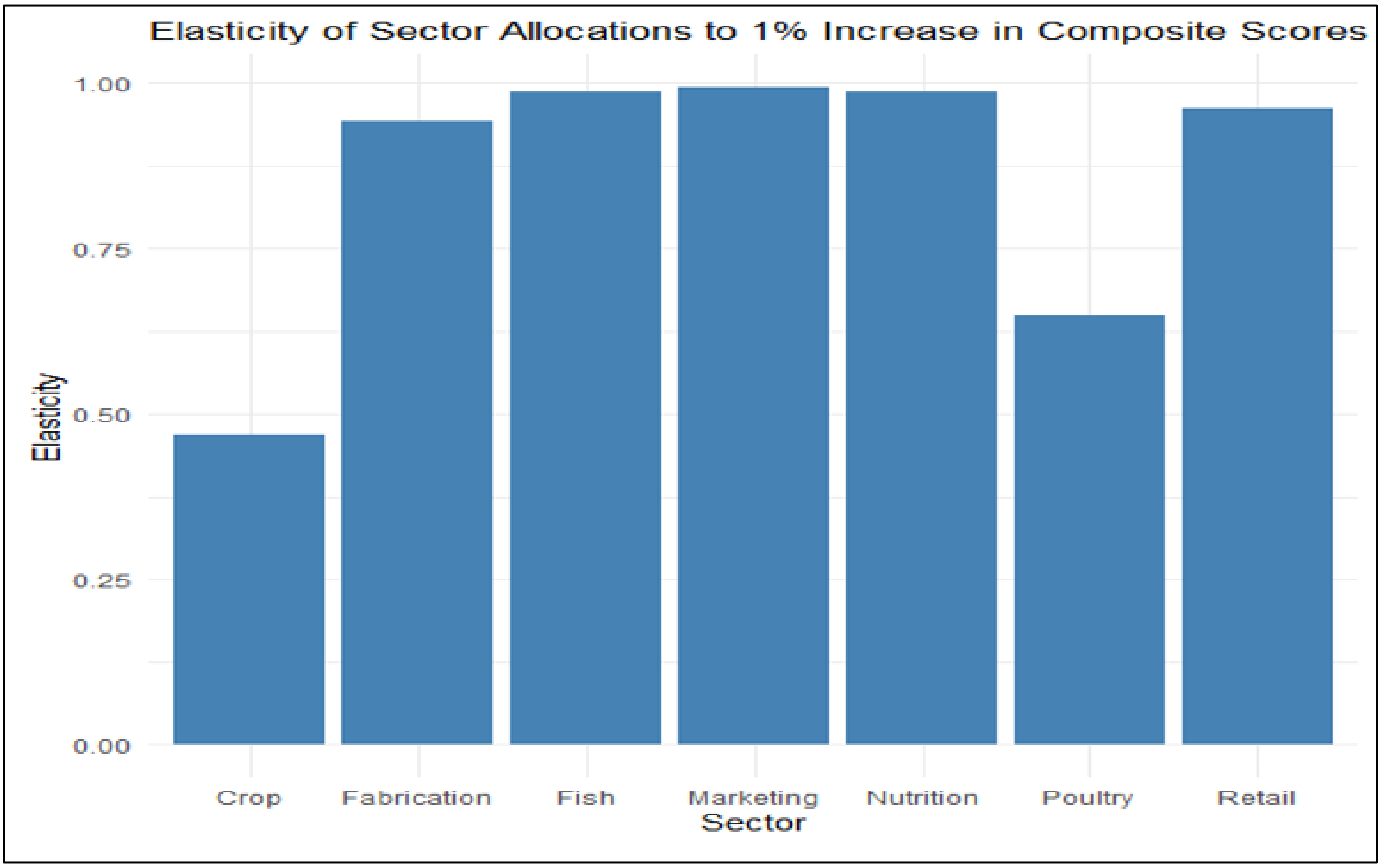


Fig 5 Elasticity of Sector Allocations to Composite Score Changes in LIFE-ND Optimization

The result presented in Figure 5 illustrates the elasticity of sectoral allocations in response to a 1% increase in their composite scores within the LIFE-ND multi-objective optimization model. Notably, Fish, Marketing, Nutrition, Fabrication, and Retail sectors show elasticities close to or equal to 1, indicating that their allocations are highly responsive to score changes any improvement in these scores would proportionally increase their allocated weights. In contrast, Crop and Poultry sectors display lower elasticity (around 0.45 and 0.65 respectively), suggesting that their allocations are less sensitive to incremental score changes, likely due to their already dominant positions. This highlights an opportunity: marginal improvements in underrepresented sectors can yield competitive allocation shifts, supporting diversification and inclusion of less dominant agribusiness sectors. Policymakers can use this insight to strategically boost sectors with high responsiveness to achieve balanced development outcomes.

## IV. DISCUSSION OF RESULT

The findings of this study reveal a strong dominance of crop production in the optimized investment model, with the crop sector receiving 70% of the total allocation and contributing significantly (9.23 units) to the overall objective function (Z), followed by poultry with a smaller allocation but a relatively high contribution (3.37 units). The remaining sectors—fish, nutrition, retail, fabrication, and marketing, each received the minimum allocation (0.05) and contributed minimally to Z, suggesting limited perceived efficiency or lower systemic impact under the current parameters. Sensitivity analysis underscores the model's high dependence on the crop sector: a 10% increase or decrease in its composite score substantially shifts its contribution to Z (from 12.91 to 15.79), while other sectors remain static. Elasticity analysis further confirms that underrepresented sectors like fish, nutrition, and marketing are more responsive to score improvements, highlighting strategic opportunities for inclusion. These results align with the reviewed literature, particularly Guo et al. (2020) and Popova & Adamenko (2022), who emphasize the need for systems-level planning and inclusive innovation in agriculture. Moreover, the model addresses the research gap noted by Vostriakova et al. (2021) and Tulush & Radchenko (2022) by offering an evidence-based, multi-objective framework for investment distribution that accounts for both impact and equity. The practical implication is clear: while economic efficiency remains crucial, achieving inclusive growth and sustainability in Nigeria's agricultural value chains requires deliberate support for less dominant but socially critical sectors. This study offers policymakers a robust tool to balance high-yield investments with broader developmental goals, resonating with global shifts toward resilient, inclusive agri-food systems.

## V. CONCLUSION

This study was able to develop and apply a Multi-Objective Linear Programming (MOLP) model grounded in Multi-Criteria Decision Analysis (MCDA) and the Triple Bottom Line (TBL) framework to optimize resource allocation across seven agribusiness value chains within the

LIFE-ND initiative. The findings reveal a marked dominance of the crop production sector in both allocation and contribution to system-wide performance, underscoring its economic efficiency. However, sectors such as fishery, nutrition, marketing, and fabrication, despite their lower composite scores exhibited higher elasticity, indicating that even modest improvements in their scores could yield proportionate gains in allocation. This suggests untapped potential and strategic opportunities for diversification and social impact. The model's sensitivity and threshold analyses further demonstrate the importance of balancing efficiency with equity to avoid systemic dependence on a single sector.

Based on the findings of the present study, it is recommended that policymakers adopt a multi-criteria allocation framework that balances economic efficiency with social impact, thereby reducing the overconcentration of resources in crop production. Strategic investments, including targeted subsidies and capacity-building efforts, should be directed toward underrepresented sectors such as nutrition, fishery, and marketing, which demonstrated high responsiveness to performance improvements. Federal and state agricultural planning bodies are encouraged to institutionalize the use of Multi-Objective Linear Programming (MOLP) integrated with Multi-Criteria Decision Analysis (MCDA) to support evidence-based and sustainable value chain development. Additionally, the enforcement of minimum investment thresholds across all sectors is essential to promote gender equity, youth employment, and environmental sustainability.

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