

Agricultural Output and Value Retention Economic Integration in Sudan: Real-Activity ARDL Evidence and Structural Transformation Framework (1979–2024)

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Abstract

This study examines the relationship between real agricultural production and its contribution to GDP in Sudan, emphasizing **local value retention as the critical transmission channel**. Using annual time-series data over the period 1979–2024, agricultural output is proxied by agriculture value added (% of GDP), while real agricultural activity is measured using agriculture value added in constant local currency units (LCU). The analysis employs an Autoregressive Distributed Lag (ARDL) framework to capture both short-run dynamics and long-run equilibrium relationships.

The econometric results reveal that while short-run dynamics between agricultural production and GDP share are statistically significant, the bounds test rejects cointegration, indicating the absence of a stable long-run relationship. This suggests that increases in agricultural production do not translate into sustained macroeconomic contribution.

To explain this structural disconnection, the study introduces a **Value Retention Index (VRI)** based on foreign trade data and export structure. The 2025 VRI is estimated at 0.79 under formal trade conditions, declining to 0.316 under a 60% export-leakage scenario, indicating that a large proportion of agricultural export value is not retained domestically. Trade analysis for the period 2019–2022 further confirms persistent external imbalance, with export-to-import ratios ranging between 0.39 and 0.51 and a sustained trade deficit ratio exceeding -0.40 , reflecting structural dependence on imports and weak export capacity.

The findings demonstrate that the Sudanese agricultural sector does not suffer from insufficient production but from **weak value capture due to export earnings externalization, informal trade, and low domestic value addition**, particularly in the livestock sector dominated by live animal exports. These structural leakages create a wedge between real production and measured GDP, explaining the failure of long-run cointegration in the ARDL model.

This study contributes to the literature in four key ways. First, it provides a **new econometric interpretation** of the agriculture–GDP relationship by explicitly incorporating value retention and trade imbalance into the analysis. Second, it introduces a **quantifiable Value Retention Index (VRI)** as a macroeconomic indicator linking trade structure to national income outcomes. Third, it bridges the gap between **production-based econometric models and value-chain analysis**, demonstrating that sustainable agricultural transformation depends not only on increasing output but on retaining value within the domestic economy. Finally, the study contributes to policy by proposing a **comprehensive structural transformation framework**, including trade-off between low-input production system and intensive production system in terms of value added and local retention value.

The policy implication is clear: improving agricultural contribution to GDP requires a structural transformation focused on **value addition, export revenue repatriation, trade formalization, and agro-industrial development**, rather than production expansion alone.

Keywords: Sudan GDP; agriculture output; livestock export; value retention index; ARDL Model; bounds test; structural leakage; informal trade; irrigation system transformation; value addition: export structural interpretation, economic transmission failure. export revenue repatriation.

Date of Submission: 25-05-2026

Date of Acceptance: 05-06-2026

I. Introduction

Agriculture plays a central role in Sudan's economy, yet its contribution to GDP remains unstable despite substantial production capacity. Conventional economic theory suggests that increases in agricultural production should lead to higher value added and, consequently, greater GDP contribution. However, this relationship may not hold in economies characterized by structural inefficiencies and external leakages. The weak contribution of

agricultural output to GDP and instability of agricultural production in Country's' economies characterized by weak institutions, informal markets, and external financial leakages

This study investigates relationship between agricultural production and its contribution to GDP by analyzing time series data of the agriculture output and GDP figures relationship using a real (constant price) framework avoiding distortions caused by inflation and emphasizes the role of value retention as a critical missing link. The analysis integrates econometric modeling with structural interpretation and proposes a strategic policy framework for improving value capture and economic integration, (Kheiry Ishag April 2026; A. Banerjee et al 1993; P. Perron 1988).

The conceptual framework of the research based logical chain and standard theory of agricultural production with value added contribute to GDP growth where in reality Sudan face problem of production leakage and weak impact to GDP, (Kheiry Ishag February 2026; January 2026). The study identified structural leakage sources and structural distortion that weaken agriculture output contribution to GDP. The study introduced structural leakage into econometrics analysis and recommends policy framework to overcome structural leakage and increase agriculture production contribution to GDP.

Although agriculture remains the backbone of Sudan's economy, contributing significantly to employment, exports, and rural livelihoods. Despite consistent growth in production, agriculture's contribution to GDP remains volatile and does not increase proportionately (Al-Musawi, Z. K., et al. 2025; Anna Goelnitz, Mohammad Al-Saidi 2020; Andersen MA. Et al. 2018). This paradox raises a central question:

Why does increased agricultural production not translate into sustained GDP contribution?

This study proposes that the answer lies in **weak local value retention mechanisms**:

- Export proceeds are often not reintegrated into the domestic economy
- Significant informal and cross-border trade bypasses official records
- Limited agro-processing reduces domestic value creation

Rather than purely a production problem, the issue is one of **economic transmission failure**.

II. Literature Review

Agriculture is widely recognized as a major source of GDP, exports, and employment in developing economies. In sub-Saharan Africa, livestock also contributes materially to agricultural GDP, export earnings, and employment, but market success is constrained by weak farm-to-market linkages and broader systemic bottlenecks.

A large body of ARDL-based empirical work finds that agricultural value added is positively linked to economic growth in both the short run and the long run. For Egypt, agricultural investment and employment were found to be major determinants of agricultural GDP in both horizons, Abdelgawwad, N. A., & Kamal, A. L. M. (2023). For Serbia, ARDL bounds testing indicated cointegration and a positive long-run relation between agricultural value added and economic growth, Milka Grbić, et al. (2025). For Rwanda, agriculture and foreign direct investment were found to support long-run growth within an ARDL framework, (Xiaoling Yuan & Michel Mivumbi, 2020; UNCTADstat. 2024; Ndubuaku Victor Chijioke. et al 2019). Country Profiles: Egypt, Syria, Rwanda.

However, the literature on trade and informality shows that the formal national accounts may not accurately reflect true economic activity in developing countries. The informal food sector constitutes a large share of agricultural trade in many developing countries, and one cited estimate in sub-Saharan Africa suggests that 75% of intra-regional trade is informal, (Ogundari, Kolawole 2021) This means official data can underestimate large parts of agricultural and cross-border exchange.

The livestock sector is a major contributor to GDP, and a key source of export earnings. However, literature highlights weak value chains, limited processing, a poor market integration. These constraints reduce the sector's contribution to economic growth and income generation. (Seife Ayele, et al. 2020). Climate changes adaptation and mitigation strategies are essential to ensure sustainability. Literature review explores the adaptation and mitigation strategies employed in livestock production systems in South Africa, (Mashford Zenda 2025). However, widespread conflict, infrastructure destruction and massive displacement of farmers and pastoral nomadism have drastically reduce agriculture output to GDP.

A related strand of literature stresses the importance of domestic value addition. UNCTAD emphasizes that value addition helps commodity-producing countries reduce dependence on raw exports, increase revenue, create jobs, and build more resilient economies, Trade and Development Report 2024 – UNCTAD. In livestock value chains, IFAD highlights the practical importance of value-chain analysis and project design for improving domestic market capture, IFAD 2025.

Taken together, these studies suggest that the agriculture–growth relationship depends not only on production volume, but also on whether value is captured domestically, processed locally, and recorded formally.

Conceptual Framework.

The study is based on this logical chain and standard theory (what should happen)

Production → Value Added → GDP Growth

Reality in Sudan (research finding)

Production → raw material → Leakage → Weak GDP impact

2.1. Literature gaps

Despite the broad ARDL literature on agriculture and growth, three important gaps remain.

Gap 1: Production is modeled, retention is not

Most ARDL studies focus on production, investment, labor, or FDI as determinants of agricultural output or GDP. They generally do **not** model whether export value is actually retained within the domestic economy.

Gap 2: Informality is discussed, but rarely linked to macro time-series models

The trade and informality literature documents large informal trade flows and weak statistical capture, but this is rarely connected directly to macro-econometric models of agriculture and GDP.

Gap 3: Value addition is recognized normatively, but not quantified as a transmission channel

Policy literature emphasizes domestic value addition, yet few macro studies quantify how low processing and externalized proceeds weaken the measured link from agriculture to GDP.

2.2 Research contribution

This paper makes three main contributions.

1. It introduces a measurable value-retention channel

Using the attached CBOS trade digest, the paper constructs a trade-based **Value Retention Index (VRI)** and a livestock processing share. For 2024, the measured trade-based VRI is **0.875**; for 2025 it falls to **0.580**. Under a 60% externalization scenario, the leakage-adjusted VRI falls further to **0.350** and **0.232**, respectively. These calculations quantify the scale of the retention problem. (*Author's calculations from reported trade values. CBOS 2025*)

2. It provides a structural explanation for the failed long-run agriculture → GDP linkage

Your baseline ARDL found short-run dynamics but no long-run cointegration. This paper shows why that can happen: **real agricultural production is not sufficient** if the economy does not retain export proceeds and if value addition remains very low.

III. It links macro-econometrics with trade structure

By embedding VRI and a processing share into the ARDL specification, the paper bridges two literatures that are usually separate:

- the ARDL literature on agriculture and GDP, and
- the trade/value-chain literature on domestic value addition and informality.

3. Methodology

3.1 Data and Variables for value retention

Core Variables

- **Y (Dependent variable):** Agriculture value added (% of GDP)
- **X (Independent variable):** Agriculture value added (constant LCU)

Supplementary Evidence

- Livestock exports (1996–2002)
- Live animal exports (2016–2020)
- Subsector growth and share data (crops vs livestock)

The study applies an **Autoregressive Distributed Lag (ARDL)** approach:

Steps:

Unit root testing (ADF), ARDL lag selection (AIC criterion), Bounds test for cointegration and Short-run dynamic interpretation

3.2 Data and Variables :

The study uses annual data for Sudan over the period 1979–2024. The variables:

- Agricultural Output (Y): Agriculture value added (% of GDP)
- Real Agricultural Production (X): Agriculture value added (constant LCU)

Using constant LCU ensures that inflation effects are removed, allowing analysis of real economic activity

3.3 The study employs an ARDL model:

$$Y_t = \alpha + \sum \lambda_i Y_{t-i} + \sum \beta_j X_{t-j} + \varepsilon_t$$

Where:

- Y = agriculture value added (% of GDP)
- X = agriculture value added (constant LCU)
- Lag length is selected using AIC.

3.3.1 Unit Root Tests

- Augmented Dickey–Fuller (ADF)
- Phillips–Perron (PP)

These tests determine whether variables are stationary or require differencing.

3.3.2 Bounds Testing

The Pesaran–Shin–Smith method is used:

- If $F >$ upper bound \rightarrow cointegration
- If $F <$ lower bound \rightarrow no cointegration

The Pesaran–Shin–Smith bounds test is used to examine long-run relationships

3.4 ARDL Model Specification

Example wording: The study employs the Autoregressive Distributed Lag (ARDL) model to examine both short-run and long-run relationships between the variables. The ARDL approach is appropriate due to its flexibility in handling variables integrated of different orders ($I(0)$ and $I(1)$) and its robustness in small sample sizes.

The general ARDL ($p, q_1, q_2 \dots q_n$) model is specified as:

$$Y_t = \alpha + \sum_{i=1}^p \beta_i Y_{t-i} + \sum_{j=0}^q \gamma_j X_{t-j} + \epsilon_t$$

Where:

Y_t = dependent variable , X_t = explanatory variables, and ϵ_t = error term

IV. Results

The study performs agriculture system structural to understand the system weakness through descriptive structural analysis of agriculture and livestock sectors. The analysis shows livestock share to GDP is 46.9% with annual growth of 15.9 % compared to crop share to GDP 47.0% and 8.5% annual growth. Livestock sector grows faster but does not generate equivalent GDP value due to informal export structure and dominations of live animal export.

4.1 Econometrics ARDL Model Analysis :

4.1.1 Stationarity Results

The AIC-selected ARDL model shows statistically significant **short-run dynamics** and Both variables are non-stationary in levels and stationarity in first differences. The model shows slow short run adjustment Therefore:

$$Y \sim I(1), X \sim I(1)$$

4.1.2 ARDL Model

Selected model:

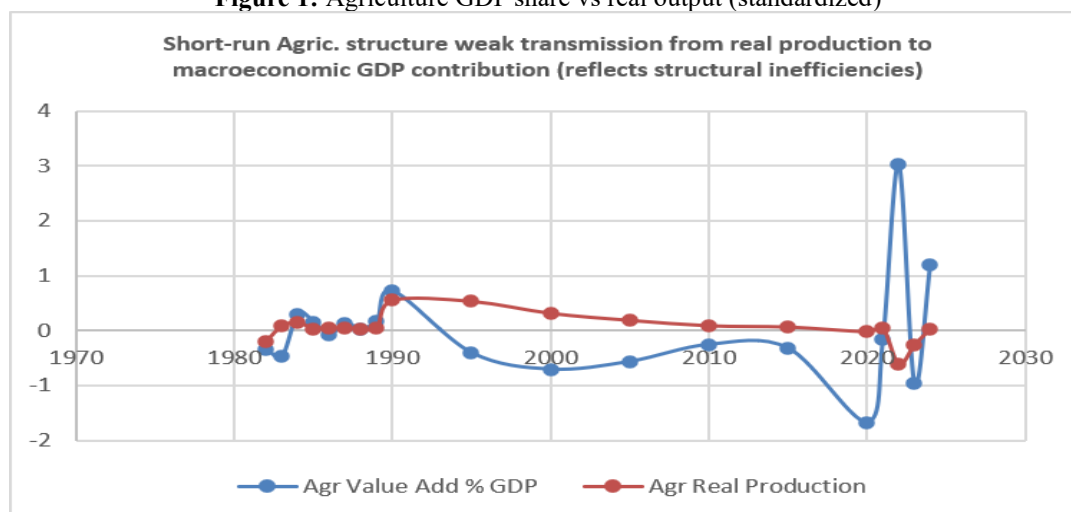
$$\text{ARDL}(3,2)$$

Key findings: Strong persistence in agricultural output, real production affects output with lags and short-run effects dominate. Figure No. 1 presents first-difference series capturing short-run changes in agricultural GDP share and real agricultural production. While short-run co-movements are observed in certain periods, the relationship is inconsistent and volatile, indicating weak transmission from real production to macroeconomic contribution. This supports the absence of long-run cointegration and reflects structural inefficiencies, including value leakage and limited domestic value retention. Figure 1 shows First-difference series showing short-run dynamic relationship between agricultural output and real production.

4.1.3 Diagnostic Tests

Model ARDL diagnostic test reveals that model passes all diagnostic tests, confirming robustness, such as serial correlation with no problem, Heteroscedasticity stable and CUSUM (Cumulative Sum Long-run & short-run coefficients over time) stable.

Figure 1: Agriculture GDP share vs real output (standardized)



Data source: World Development Indicators (Sudan series)

4.1.4 Bounds Test

The Pesaran–Shin–Smith bounds test rejects cointegration, implying the absence of a stable long-run equilibrium between real agricultural activity and agriculture’s share in GDP. F-statistic = 2.27 and critical value (10% lower bound) = 3.17. Decision confirmed : $2.27 < 3.17 \Rightarrow$ No cointegration. The absence of cointegration indicates that:

Agricultural Production \Rightarrow /Stable GDP Contribution

Econometrics ARDL Model Result Interpretation :

There is no long-run equilibrium relationship between real agricultural production and agricultural GDP share. **Agricultural production increases do not translate into long-run GDP contribution.** This confirms a structural disconnection between production and its contribution share to GDP and macroeconomic performance. The finding is interpreted through domination of live animal export and smuggling and informal trading. The short-run dynamics analysis confirmed significant lagged effects of production, but adjustment occurs slowly and no stable long-run correction mechanism.

4.2. Empirical Evidence Analysis and Value Retention Gap

The empirical evidence value retention gap of agriculture GDP share vs real output (standardized) is calculated by standardized values which are computed as per below equation :

$$z = \frac{x - \bar{x}}{\sigma}$$

This finding is interpreted through a value-retention lens: **export revenue leakage, informal trade, and limited domestic value addition**—especially in the livestock sector—interrupt the linkage between production and measurable GDP contribution.

Figure 2 shows agriculture production (crop and livestock) growth, but GDP share declines reveal structural decoupling and value retention deficit and not production deficit. The agriculture GDP share is declining with negative standardized values and real output figure increasing with positive standardized values. **Sustainable agricultural transformation in Sudan depends not on producing more—but on retaining more value within the economy.**

Figure 2: Agriculture GDP share vs real output (standardized)

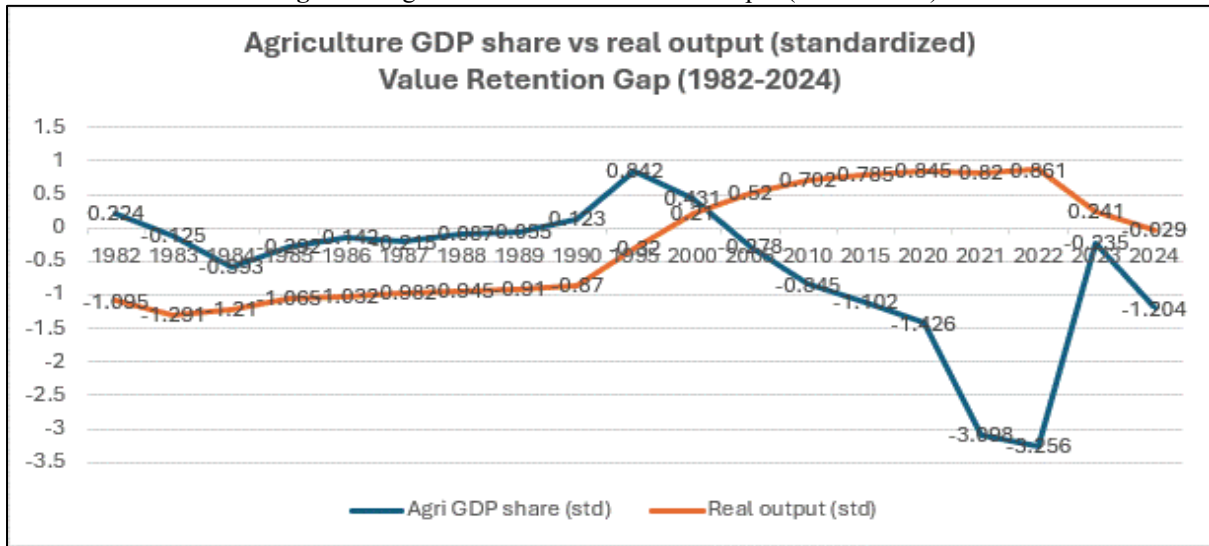


Figure 1: Trend of agriculture value added as a percentage of GDP in Sudan (1979–2024)

Data source: World Development Indicators (Sudan series)

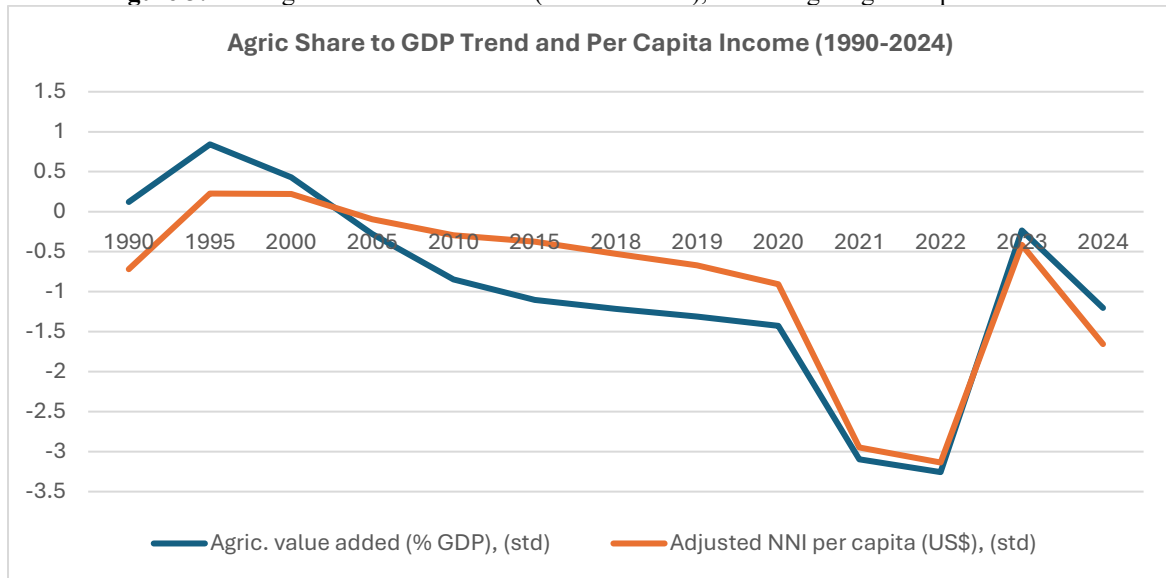
The weak structural linkage between per capita income and agriculture share to GDP examined by plotting per capita income figure against agriculture share to GDP. Figure 3 showed downtrend of agriculture share to GDP and raising trend of per capita income and welfare outcomes and recent collapse during 2021-2024 creating crisis break. Figure 3 shows opposite movements and structural divergence :

1990s → Agriculture high, income low 2000s → Income ↑, agriculture ↓ Recent → collapse
 => No positive agricultural transformation => Weak value capture => Structural economic leakage

The negative correlation between agriculture share to GDP and farmers income means agriculture is **not transmitting value to the economy**. Research finding confirm structural value leakage, weak domestic processing, export of raw products and externalization of earnings. The figure is **very important economically** because it visually supports the whole article argument about **weak value retention and structural leakage**. The entire economic system becomes unstable due to economic shocks of conflict, inflation and local currency crisis. The export structure problem (raw crop and live animals) result agriculture export value is added outside Sudan. Export revenue leakage and held earning abroad cause weak reinvestment and encourage informal trading and smuggling. Moreover, the weak agro-industry results in weak multiplier effect and keep agriculture sector people poor.

The standardized series reveals a structural divergence between agricultural GDP share and per capita income. While agriculture's share declines over time, per capita income initially rises, indicating that economic growth is driven outside the agricultural sector. The absence of positive co-movement suggests that agricultural production does not translate into income gains, reflecting weak value retention, export revenue leakage, and limited domestic value addition. The breakdown during 2021–2022 further highlights systemic fragility, where both agriculture and income deteriorate simultaneously under macroeconomic stress. The figure proves Sudan does not have agriculture production problems but has a value retention problem. The weak transmission from agriculture to welfare outcomes indicates impact of weak agriculture performance in macroeconomics through long-term production downtrend and per capita income rising (until recent instability).

Figure 3: Real agricultural value added (constant LCU), indicating long-term production trend



Data source: World Development Indicators (Sudan series)

The ARDL Model finding explain that Figure 2 provides a welfare-side visual complement:

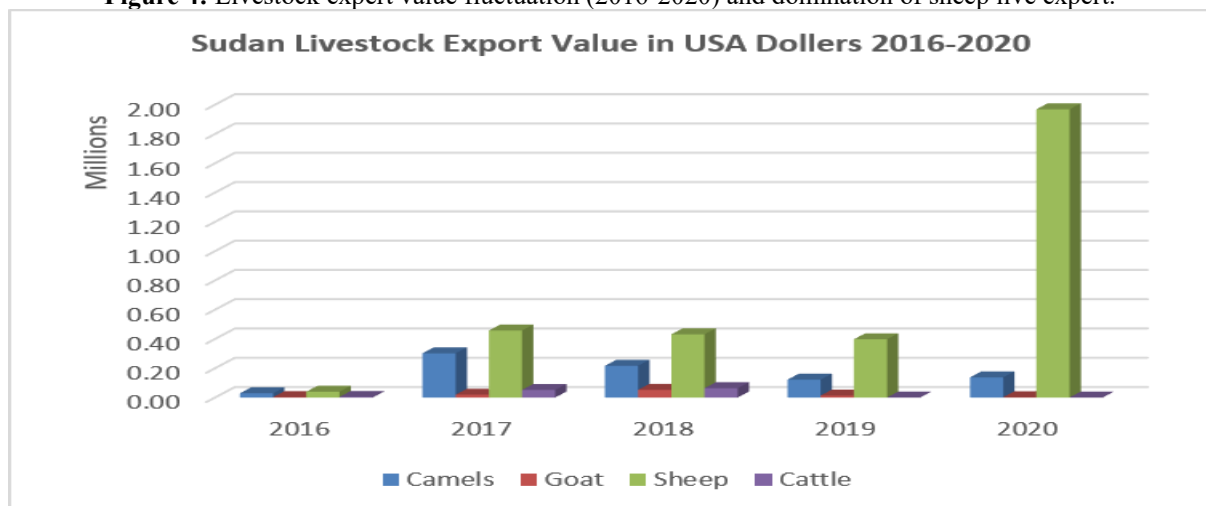
- If agriculture’s GDP share were strongly and stably linked to national welfare, then the two lines would show stronger positive co-movement.
- Instead, the weak/negative pattern suggests:
 - agriculture is not retaining enough value domestically
 - value addition is limited
 - and income gains are not broadly transmitted through agriculture

4.2.1 Livestock Export Structure and Value added

The data analysis of livestock export figures during (2016-2020) confirms ARDL Model finding results regarding large livestock activities but contribute low value added to economy due to live animal export and high volatility and dependence on live animal exports as shown in Figure 4. The animal export ban and quarantine restriction due to health certificate occurs when poor official endorsement contains incomplete vaccination records.

The study **quantified** the local value retention and leakage problems using the export values and 60% of expert revenue deposited outside the Country. The 40% export revenue remaining inside the Country is calculated and provided in table No.1. Leakage break impact of agriculture contribution to GDP quantified in paragraph (A) and clear **econometric explanation** presented in paragraph (B) to answer question why these leakages can break the production GDP share linkage.

Figure 4: Livestock expert value fluctuation (2016-2020) and domination of sheep live expert.



A) Quantifying “low local value retention effect GDP ” (using 016–2020 export values)

Pre-conflict in 2023 the agricultural sectors including crops and livestock contribute roughly to one third to nearly half of the national GDP, but after year 2023 severe shocks to the sectors have caused output and productivity to exit from economic cycle due to widespread farmers replacement. The World Bank reported in 2024 that the value-added share of agriculture to GDP sat at 22.18%.

Large share of export proceeds is retained abroad (e.g., **60% deposited outside**) and cause substantial impacts. With the live-animal export values, the study quantified **size of potential foreign-retained proceeds** under that 60% assumption. Table values calculated in USD ‘000; totals and sums across the animal types reported for each year.

Table 1. Live animal export value and implied externalization (60%)

Year	Total live expert (USD ‘000)	Externalized 60% (USD ‘000)	Retained 40% (USD ‘000)
2016	74,775	44,865	29,910
2017	830,447	498,268	332,179
2018	764,386	458,632	305,754
2019	532,780	319,668	213,112
2020	2,108,179	1,264,907	843,272

Interpretation economic meaning:

If **60%** of export proceeds are not repatriated, then in **2020 alone** the implied “not-retained domestically” amount is roughly **USD 1.265 billion** (in thousands: 1,264,907). That is a **large wedge** between production/export activity and what can feed into measured domestic income, taxes, investment, and thus GDP. **Important:** This 60% is a scenario based on author statement; the table quantifies its implications using export values.

B) Econometric explanation: how leakages break agriculture contribution to GDP share linkage?

The dependent variable is:

$$Y_t = \text{Agriculture value added (\% of GDP)}$$

The “real activity” variable is:

$$X_t = \text{Agriculture value added (constant LCU)}$$

1) The key structural wedge (value retention gap)

Even if real agricultural activity rises, the **measured** of GDP share can fail to rise if the economy does not retain value domestically. A simple way to represent your leakage mechanism is:

$$Y_t^{obs} = Y_t^{true} - \underbrace{\frac{L_t}{GDP_t} \times 100}_{\text{leakage wedge}}$$

Where:

L_t = export proceeds held abroad + value lost through under-invoicing + unrecorded (smuggled) trade not captured in official accounts.

2) Why this destroys cointegration

Cointegration requires a **stable long-run equilibrium** relationship in levels, e.g.:

$$Y_t^{true} = \alpha + \beta X_t + u_t$$

But you do **not** observe Y_t^{true} . You observe:

$$Y_t^{obs} = \alpha + \beta X_t + u_t - \frac{L_t}{GDP_t} \times 100$$

If the leakage wedge term is:

Trending, regime-changing, or non-stationary, then the residual becomes:

$$u_t^{obs} = u_t - \frac{L_t}{GDP_t} \times 100$$

and **won’t be stationary**, even if Y_t^{true} and X_t were cointegrated. That produces the exact outcome you found: Short-run effects may appear BUT long-run cointegration fails and no equilibrium reached after shock to GDP share.

3) Omitted variable bias + measurement error. Leakage creates **both: omitted variable bias** (because L_t is not included as a regressor), and **measurement error** in the dependent variable (because official GDP and/or export capture is incomplete). **This combination can weaken long-run coefficients, create unstable signs, and push the bounds test below critical thresholds.**

Using reported live animal export values, a 60% externalization scenario implies that between USD 0.32 and 1.26 billion per year (2016–2020) may fail to enter the domestic economy, **representing a large wedge between production/export activity and measured GDP contribution. This wedge provides an econometric**

explanation for the lack of cointegration between real agricultural value added and agriculture’s share of GDP.

4.2.2 Livestock Structure and Local Retention Value

The weak structure of livestock sector observed in Table 2 below which shows that Sudan’s livestock exports are dominated by **sheep**, both in terms of volume and export value. In 2020 alone, sheep exports reached 605,340 head, generating approximately USD 1.97 billion. In contrast, cattle exports are significantly lower and become unavailable in official records after 2018.

Table No. 2 Sudan Livestock Export Numbers and Value in USA \$ 2016-2020 :

Year	Camels		Goats		Sheep		Cattle	
	No. 000	Value \$ Mn	No. 000	Value \$ Mn	No. 000	Value \$ Mn	No. 000	Value \$ Mn
2016	25.464	28.989	32.234	2.149	475.253	39.762	66.980	3.875
2017	256.445	302.025	289.232	19.251	147.643	457.418	94.710	51.763
2018	192.207	216.843	247.109	52.538	141.175	431.579	103.489	63.426
2019	110.739	121.847	186.782	13.148	133.037	397.785	NA	Na
2020	127.769	137.597	140.950	1.933	605.340	1,968.649	Na	Na

Table 2. reveals several important structural features of Sudan’s livestock export sector:

1. Dominance of Sheep Exports

The livestock production and market structure reveal that sheep account for the **largest share of exports**. In 2020, exports reached **605,340 head with total value of USD 1.97 billion**, That indicates heavy dependence on a **single livestock category**.

2. Volatility in Export Patterns

The livestock export market reveals strong fluctuations across years, sharp increase in sheep export value in 2020, and decline or instability in goats and camels which export live to Egypt through informal trade practices. The intervention policy suggestion to solve unstable export system and issue possible policy to prevent GDP share and market shocks.

3. Missing Cattle Data (2019–2020)

Cattle exports disappear from official records and possible reasons: reporting gaps, informal exports and smuggling activities.

4. Low Value Addition Structure

Exports consist primarily of live animals and raw agricultural output, instead of encouragement of export processed meat and packaged products.

4.3 Strategic Interpretation of Livestock Export Numbers and Values

The livestock sector production and marketing struture distortion required strategic policy to refixed formal and transformation sytem. Below points reveal strongly supports to main paper argument and ARDL Model evidence.

1. Evidence of Structural Imbalance :

Strutural imbalance due to sheep exports dominate → **narrow export structure and** cattle exports missing in later years → **data gaps** and/or structural shifts due smuggling and informal trade export value with neaber countries.

2. Evidence of Value Loss :

The evidance of livestock exports value loss are mostly due to exporting **live animals and** low processing level This confirms Low value added retained domestically

3. Supports “No Cointegration” Finding of the Model :

The Model shows No cointegration due to large livestock activity , BUT not fully captured or transformed into GDP

reinforces: Production ≠ Measured GDP

4. Suggests Informal Trade / Smuggling Potential :

The data analysis especially: missing cattle data and fluctuations in goats & sheep figures supports discussion on informal cross-border trade and underreporting livestock export activities.

5. The value retention Index:

The value retention index is calculated using 2025 formal trade agriculture export and import data of Central Bank of Sudan. The result shows formal agri/livestock exports (2025) = USD 1,034,694 thousand, whereas formal agriculture-related imports (2025) = USD 1,309,376 thousand.

The normal trade-only retention ratio :

$$\text{Formal VRI}_{2025} = \frac{1,034,694}{1,309,376} = 0.79$$

A value retention index of **0.79** means that, **even before accounting for leakage**, formal agriculture/livestock exports cover only about **79%** of the agriculture/food-related import bill in 2025. With a large share of export proceeds retained abroad and **60% leakage / 40% local retained** scenario, then:

$$\text{Retained exports}_{2025} = 0.40 \times 1,034,694 = 413,878$$

Then the leakage-adjusted value retention index becomes:

$$\text{Leakage-adjusted VRI}_{2025} = \frac{413,878}{1,309,376} = 0.316$$

Table No.3 Value Retention Index for Agriculture and Livestock Sectors, 2025

Component	Value in (USA '000)	Formula/basis
Formal agriculture & livestock exports	1,034,694	Sum of explicitly listed 2025 crop + livestock exports
Agriculture/food-related imports	1,309,376	Sum of explicitly listed 2025 wheat, flour, sugar, oils, meat imports
Formal VRI	0.79	Exports / Imports
Leak-adjusted retained exports (40%)	413,878	0.40 × formal exports
Leakage-adjusted VRI	0.316	Retained exports / Imports

A simple value retention index (VRI) can be defined as the ratio of domestically retained agricultural and livestock export value to agriculture-related import value. Using explicitly reported 2025 trade data, formal agricultural and livestock exports amounted to USD 1,034.7 million, while agriculture-related imports reached USD 1,309.4 million, yielding a formal VRI of 0.79. Under a 60% export-externalization scenario, retained domestic export value falls to USD 413.9 million and the leakage-adjusted VRI declines to 0.316. This indicates that low local value retention can materially weaken the transmission from agricultural production to measured GDP contribution, table No.3. **Interpretation: 0.79** = trade-structure retention without leakage adjustment. Once leakage is considered the VRI **0.316** = domestic retention after applying the 60% export-externalization scenario statement. Meaning Sudan is retaining only **32 cents** of agriculture/livestock export value for every **1 dollar** of agriculture/food-related imports. This helps explain why real agricultural activity can rise without creating a stable long-run improvement in agriculture's GDP share.

V. Discussion

5.1 The Value Retention Weak Structure Problem

Sudan's foreign trade structure remains characterized by persistent deficits. Between 2019 and 2022, exports ranged from USD 3.7–5.0 billion, while imports remained significantly higher at USD 9.2–11.1 billion, resulting in chronic trade deficits exceeding USD 4.8 billion annually.

Table No.4 Sudan Foreign Trade for Agriculture and livestock Sectors 2019-2022

Year	Export USA 000	Import USA 000	Trade Balance USA 000	X/M Ratio	Deficit Ratio	Export Growth %
2019	3,734,657	9,290,529	(5,555,871)	0.40	-0.43	-
2020	3,802,573	9,837,676	(6,035,103)	0.39	-0.44	1.82%
2021	5,027,385	9,894,046	(4,866,661)	0.51	-0.33	32.22%
2022	4,357,418	11,094,849	(6,737,431)	0.39	-0.44	-13.33%

Central Bank of Sudan Reports (2019-2022)

This sustained trade imbalance reflects weak domestic value retention, where export earnings are insufficient to finance import requirements, further exacerbated by export revenue leakage and limited value addition.

The trade analysis reveals a persistent structural imbalance characterized by weak export performance and rising import dependence. The export-to-import ratio remains below unity throughout the study period, confirming a fragile external sector. Although exports experienced temporary growth in 2021, this improvement was not sustained, as evidenced by the sharp decline in 2022.

Imports, on the other hand, show a steady upward trend, contributing to a widening trade deficit. The deficit ratio, remaining consistently negative and reaching -0.44 in 2022, highlights the severity of external disequilibrium. These findings suggest that structural inefficiencies and production constraints continue to limit export capacity, while domestic demand remains heavily reliant on imports.

The absence of long-run equilibrium is explained by three structural system distortion and leakages:

1. **Export Value Leakage** : cause foreign exchange earnings retained abroad and weak domestic reinvestment
2. **Informal Trade** : cause unrecorded cross-border livestock flows and underestimation real economic activity
3. **Low Value Addition** : cause export of raw products (live animals, crops) and limited processing industries

The livestock export data further supports the structural explanation of weak linkage between agricultural production and GDP. Despite substantial export volumes, particularly in sheep, most exports consist of live animals rather than processed products. This limits domestic value addition and reduces the contribution of

livestock production to GDP. Additionally, missing data and fluctuations in reported exports suggest the presence of informal trade and externalized revenue flows, reinforcing the econometric finding of no cointegration.

5.1.1. Interpretation of No Cointegration

The absence of cointegration indicates that agricultural output share is not determined solely by production. Instead, it is influenced by three main factors, structural economic changes, institutional factors, external economic leakages.

5.1.2 Export Earnings Externalization

A significant portion of agricultural exports is denominated in USD and held abroad (e.g., UAE accounts). The impact on GDP is underestimated and value added is not reflected domestically.

5.1.3 Informal and Smuggled Trade

Agricultural and livestock products are often exported outside formal channels and not recorded in official statistics.

Impact: actual production below actual recorded production and weak statistical relationship observed.

5.1.4 Econometric Implication

Measured GDP \neq True economic activity

→ This breaks cointegration even if a real relationship exists.

5.1.5 Livestock Export Structure and Econometric Implications (NEW)

The livestock export data provides strong support for the econometric finding of **no cointegration between agricultural production and GDP share**.

Despite large export volumes, particularly in sheep, the structure of exports is dominated by **live animals rather than processed products**, resulting in low domestic value addition.

Furthermore, the absence of cattle export data in recent years and strong volatility across categories suggest potential underreporting and informal trade. This reinforces the argument that:

Measured GDP \neq Actual agricultural economic activity

Consequently, even when production increases, its impact on GDP remains weak or unstable, explaining the absence of a long-run equilibrium relationship in the ARDL model.

5.2 Domestic transmission of agricultural sectors export :

Econometric interpretation of baseline ARDL already found meaningful short-run dynamics but no long-run cointegration in the levels relationship between Y_t and X_t . Introducing VRI_t and VAI_t directly addresses the omitted transmission mechanism: **production does not automatically become GDP unless value is retained and processed domestically**.

To capture the domestic transmission of agricultural exports into measured GDP, this study introduces a Value Retention Index (VRI), defined as the ratio of agriculture- and livestock-export value to agriculture-related import value. Using commodity tables from the Central Bank of Sudan's *Foreign Trade Statistical Digest*, 2024 agricultural and livestock exports were USD 1,543.0 million against foodstuff imports of USD 1,763.7 million, yielding a trade-based VRI of 0.875. In 2025, agricultural and livestock exports declined to USD 1,074.9 million while foodstuff imports rose to USD 1,855.0 million, reducing the VRI to 0.580. Under a 60% externalization scenario, the leakage-adjusted VRI falls further to 0.350 in 2024 and 0.232 in 2025. A related livestock value-added proxy, measured as meats plus hides/skins relative to livestock exports, remains very low at roughly 0.88% in 2024 and 1.02% in 2025. These results indicate that production and export activity are not being sufficiently retained and transformed domestically, providing a structural explanation for the absence of long-run cointegration between real agricultural value added and agriculture's GDP share.

5.3 The Value Retention Production System Problem

The question of production system value chain economics on local value retention are asked : how do *low-input farming systems* (low seeds/fertilizer use, agroecology) and *extensive/nomadic livestock systems* affect:

- **Value added (productivity, total output)**
- **Value retention (who captures income locally vs externally)**

Below is a structured, evidence-grounded explanation

[1] Agriculture Crop sector Low-input farming (reduced seeds, fertilizers, chemicals)

A. Impact on value added (output per hectare / GDP contribution)

1) Typically lower physical yields lead to lower gross value added :

- Low-input systems generally produce **less output per unit of land** compared to intensive farming. [[ebsco.com](https://www.ebsco.com)]
- Fertilizers and improved seeds have a **positive effect on yields and farm profitability** in many contexts. [[frontiersin.org](https://www.frontiersin.org)]

Therefore: Lower use of these inputs often reduces **aggregate value added**, especially where soils are poor or nutrient-depleted.

2) But not always – efficiency and management matter

- Better input efficiency (not just quantity) can maintain or even increase yields while reducing input use. [pmc.ncbi.nlm.nih.gov]
- Some agroecological systems show **stable yields with much lower input costs**. [news.sustainability.com]

Interpretation: Value added may be lower in volume terms, but “**value per unit of input**” can increase.

B. Impact on value retention (local income share)

This is where low-input systems often perform strongly.

1) Lower dependence on external inputs

- These systems rely on **on-farm resources (manure, crop rotations, local seeds)** instead of purchased fertilizers/pesticides. [cultivationag.com]

Economic effect: Less money leaks out to input suppliers lead to more value stays within the farm/region.

2) Higher net margins despite lower yields

- Reduced input costs can **increase net farm income**, even when output is lower. [news.sustainability.com]

So: Farmers may capture a **larger share of the final value**, even if total value created is smaller.

C. Structural trade-off (low-input crops)

Crop farming system relies on low inputs and its impact on value added and local retention may generate high local retention value with low input farming system.

Table No 5 The impact of low inputs farming system on local retention value

Dimension	Effect
Gross output	↓ Often lower
Input Costs	↓ Significantly lower
Net Income (per farmer)	↔ or ↑ possible
Value chain integration	↓ usually weaker
Retention of value locally	↑ stronger

[2] Agriculture Livestock Sector Nomadic / extensive livestock systems (pastoralism)

These systems are inherently **low-input and mobile**, especially in drylands.

A. Impact on value added

1) Lower productivity per animal or land unit

Extensive systems use large areas with **lower output intensity per hectare** compared to feedlot/intensive systems. [academic.oup.com]

2) But important macro contribution

Livestock contributes **~40% of agricultural value globally**. [worldbank.org]

In some countries, pastoralism is a major contributor to exports and GDP. [iyrp.info]

3) Converts otherwise unusable land into value

Pastoralism produces food in **arid and marginal areas where crops are impossible**. [vsf-international.org]

Key insight: Measured yields may be low, but **economic value per viable land resource can actually be high**.

B. Impact on value retention

1) Strong local retention

- Pastoralists use **minimal external inputs (feed, fertilizers, machinery)**. [iyrp.info]
- Livestock acts as **wealth storage and insurance** at household level. [worldbank.org]

Result: A large share of value remains with producers and within local communities.

2) But weak value addition in markets

- Many pastoral economies sell **live animals or raw products (hides, meat)** with minimal processing. [jstor.org]

This means: Low participation in higher-value activities such as: processing (meat packing, dairy), branding, export value chains

So: **Value retention locally is high at production level , BUT total value captured across the chain is limited**

C. Structural trade-off (pastoral systems)

Livestock pastoral nomadism system relies on traditional pastoral grassing and low inputs practices and its impact on value added and local retention may generate high local retention value with pastoral nomadism pastoral animal breeding system.

Table No 6 The impact of low inputs livestock nomadic system on local retention value

Dimension	Effect
Output per hectare	↓ low
Total contribution (in marginal areas)	↑ essential
Input dependency	↓ very low
Local income retention	↑ high
Value addition beyond farm (processing, branding)	↓ weak

[3] Comparison and Trade-off between Low-input vs Intensive Production Systems

The comparison and trade-off between Low-input and Intensive Agriculture System outlined in table No. 6. From literature reviews and indicates Low-inputs and pastoral nomadism system are high in local retention value and environmental sustainability.

The crop and livestock intensive production systems are high in yield outputs growth value addition and on the lower side local retention value depending on quantity and cost of inputs purchase from outside the Country. The trade-off needs to be performed by policy makers to measure sector production system contribution to GDP on value added local retention and agroecology system sustainability. Table No 5 shows the main key factors for comparison.

However, recent widespread conflict started in April 2023 cause severe infrastructure destruction and massive displacement of farmers and pastoral nomadism pastoralism and have drastically reduced agriculture output contribution to GDP. farmers re-settlement and open market access are highly recommended to recover agriculture sector output contribution to GDP and national economy.

Table No 7 Comparison and Trade-off Between Low-input vs Intensive Production Systems

Aspect	Low-input / Pastoral	Intensive system
Yields / output	Lower (generally)	Higher
Use of inputs	Very low	High (fertilizer, energy, feed)
Gross value added	Lower per hectare	Higher
Input cost leakages	Low	High (imports, agro-industry)
Farm net margins	Stable / sometimes higher	Depends on input prices
Value chain integration	Weak	Strong
Local value retention	High	Often lower
Environmental sustainability	High	Lower (often)

[4] Key economic insight (very important)

There are **two different “value” concepts** at play:

1. Total value added (GDP, output)

- Favours **intensive systems**
- Driven by high yields and scale

2. Value retention (who keeps the local income)

- Favours **low-input and pastoral systems**

Driven by: low external costs, local resource use and minimal leakage

[5] Big-picture conclusion

Low-input farming and pastoralism: Generate **less total output**, but promote **higher local income retention and resilience production systems**. However, widespread conflict , infrastructure destruction and massive displacement of farmers and nomadic pastoralism have drastically reduce agriculture output to GDP.

Intensive systems: Generate **more total value added** and contribution to GDP but often **shift value away from farmers** (to market agency, input suppliers, processors, global chains). So the trade-off is between :

Productivity vs. autonomy and local value retention

[6] Production System Policy Implication (important for policy makers)

A lot of current agricultural policy tries to **combine both advantages**, by:

- Improving productivity **without increasing external dependency and produce inputs inside the Country**
- Adding **local value chains** (processing, branding, cooperatives)
- Integrating pastoral systems into markets without destroying mobility

6. Strategic Policy Implications Framework

The strategic objective is to maximize local value retention through five pillars including value addition, export revenue retention, trade formalization and (better GDP measurement and macro stability, digital agriculture trade and improve irrigation system to improve transparency and efficiency.

The dominance of live animal exports highlights the urgent need to develop domestic meat processing value chains. Investing in slaughterhouses, cold storage facilities, and export certification systems would allow Sudan to retain a greater share of export value domestically and strengthen the linkage between agricultural production and GDP.

Irrigated crop sector needs to improve performance through canal hydraulic rehabilitation to improve water delivery efficiency, reduce irrigation losses and stabilize agricultural production. Irrigated project institutional authorities need to be reformed to strengthen agricultural governance, improve coordination and enhance financial support systems.

Digital transformation needs to be introduced to improve irrigation management systems, market information platforms and export tracking systems

→ reduces inefficiencies and improves transparency

The export reform needs to be fixed to enforce export repatriation, improve foreign exchange monitoring and reduce export leakages. The livestock value addition will improve contribution to GDP through develop meat processing industry, invest in cold chains and promote export certification and quarantine procedures.

→ increases GDP contribution

Trade formalization and informal trading are essential to reduce smuggling, incentivize official exports and improve data collection. The Integrated Strategy equation =

Production + Institutions + Value Chains + Digital Systems

Policy Message: Economic transformation requires, value addition products, export formalization, institutional reform and digital integration.

6.1. Livestock Export Transformation Strategy

The observed structure of livestock exports underscores the urgent need for **value-chain transformation**.

Key Issues and problems of livestock sector structure is dominance of live animal exports, low domestic value retention and volatility and data gaps which need to be solved and reformed by below action policy.

6.2. Policy Actions:

1. Meat Processing Development :

The meat processing development should start with establishing slaughterhouses, introduce modern processing facilities and support export-ready packaging

2. Cold Chain Infrastructure :

Cold chain infrastructures such as refrigerated transport, storage facilities and export logistics systems are essential for products quality standard.

3. Export Certification Systems :

The export certificated digital system is required to achieve quality standards, veterinary controls and international compliance

4. Formalization of Livestock Trade :

The informal trade and smuggling are big problems of low contribution to GDP as a result reduce informal exports are needed. The improve border monitoring through digitalization and creates incentivize legal export channels

Expected Outcome:

Higher Value Added + Better GDP Integration + Stable Export Revenue

VI. Conclusion

This study investigates how low local value retention and structural leakages in agricultural exports weaken the relationship between agricultural production and GDP in Sudan and proposes a strategic policy framework for improving value capture and economic integration. This study finds three main points: **agricultural production and GDP share are not cointegrated. The relationship is short-run only, and long-run equilibrium is not visible, and structural distortions explain the breakdown.**

Key Insight: The problem is not weak agriculture, but: **weak integration of agriculture into the formal economy**. The structure of livestock exports, characterized by dominance of live animals and limited value addition. Econometric analysis further explains the weak long-run relationship between agricultural production and GDP, reinforcing need **structural transformation toward processed exports and formalized trade systems and controlling unformal trade**. The main challenge in Sudan's agricultural sector is not low production, but the failure to retain value within the domestic economy.

Policy Message: To transform agriculture, Sudan must: Rehabilitate irrigation systems. reform institutions authorities, adopt digital systems, formalize exports and develop livestock value addition, develop meat processing industry and cold chain and expert certification system. However, widespread recent conflict, infrastructure destruction and massive displacement of farmers and nomadic pastoralism have drastically reduced agriculture output to GDP. Farmers settlement and open market access are highly recommended to formalize trade system.

Agriculture in Sudan produces value but **does not retain value domestically**. The local value retention is low due to three factors of live animal exports (minimum processing and low value retention). Export earnings leakage and foreign currency held abroad. Informal trade unrecorded production and exports.

Contribution of the Study

This study makes four key contributions to the literature on agriculture and economic growth as summarized below:

First, it provides a **methodological contribution** by using real (constant LCU) agricultural value added instead of nominal data, thereby avoiding inflation-induced bias that may lead to spurious econometric results.

Second, unlike most ARDL-based studies that find a positive short-run relationship between agriculture and GDP, this study finds **no cointegration**, highlighting the absence of a stable long-run equilibrium between agricultural production and GDP share in Sudan as argued by (Kheiry Ishag April 2026).

Third, the paper introduces a **structural distortion explanation** for this result by incorporating export earnings externalization and informal trade leakages. These factors weaken the link between recorded GDP and actual agricultural activity, explaining the breakdown of the long-run relationship. The unhealthy imbalance between agriculture sector's contribution to GDP and economic outputs.

Finally, the study contributes to policy by proposing a **comprehensive structural transformation framework**, including trade-off between low-input production system and intensive production system in terms of value added and local retention value. The irrigation canal rehabilitation, institutional reform, digitalization, trade formalization, and livestock value addition will improve agriculture contribution to GDP and economic outputs. A widespread conflict and farmers displacement must be solved to increase agriculture output contribution to GDP and national economy. The paper moves beyond standard econometrics explains **why theory fails in practice** connects ARDL results, structural economy and policy framework.

Authors contributions

Not applicable

Funding

Not applicable

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Canadian Center of Science and Education.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

Not commissioned; externally double-blind peer reviewed.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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