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CONTRIBUTION OF LIVESTOCK TO CO_2 EMISSION IN SAARC COUNTRIES: AN EMPIRICAL ANALYSIS OF PANEL DATA

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Abstract

This study investigates the contribution of livestock production to CO_2 emissions in SAARC countries from 1990 to 2020 through an empirical analysis using panel data. The study included variables such as CO_2 emissions and stocks, namely cattle, chickens, and goats. Data for the Maldives were excluded due to unavailability, and swine population data were also omitted for the same reason. Unit root tests revealed that the series were non-stationary at levels but became stationary after first differencing. The ARDL bounds test with a lag length of 3 (AIC = -7.951, SC = -7.060, HQ = -7.590) identified significant long-run relationships. Specifically, cattle (coefficient = 2.948, p-value = 0.000) and chickens (coefficient = 2.369, p-value = 0.000) were positively associated with CO_2 emissions, while goats showed a negative association (coefficient = −5.594, p-value = 0.000). It was proven that there was a long-term equilibrium by cointegration tests like the Kao Residual cointegration test (ADF t-Statistic = -1.646, p-value = 0.049) and the Johansen Fisher panel cointegration test (Trace test and Max-Eigen test: p-value < 1%). Cross-sectional analysis revealed variability, with Afghanistan's cointegration coefficient at -0.325 (p-value = 0.000) and Bhutan's at 0.034 (p-value = 0.000). The results showed notable variability across countries, suggesting the need for tailored mitigation strategies. The study highlights the significant role of livestock in greenhouse gas emissions and calls for improved management and regional collaboration to mitigate environmental impacts in SAARC countries.

Keywords: ARDL model, CO_2 emissions, Cointegration, Livestock production, Panel data analysis

JEL Classification: Q54, C23, F54, O13

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1. Introduction

Livestock production is vital in the global food system, supplying essential protein and nutrients. However, it is also a major source of greenhouse gas emissions, especially methane (CH_4) and nitrous oxide (N_2O), significant contributors to climate change. In the South Asian Association for Regional Cooperation (SAARC) countries, increasing populations are driving a rise in livestock production to meet the growing demand for animal products. This trend raises concerns about the environmental impact of these practices.

The Intergovernmental Panel on Climate Change (IPCC) states that the main greenhouse gases produced by livestock are methane, released through enteric fermentation and manure management, and nitrous oxide, also from manure management. Studies, such as the one conducted by Das et al. (2020) in Bangladesh, highlight the urgent need for comprehensive GHG inventories to inform policy and mitigation strategies. Although livestock significantly contributes to agricultural emissions, the energy sector is the predominant source of global emissions (Hur et al., 2024). Nonetheless, livestock management practices within agriculture are crucial targets for emissions reduction. Prior research across various regions, including India and China, has demonstrated substantial variability in emissions based on factors such as livestock type, regional practices, and economic conditions (Patra, 2017; Hao et al., 2022).

The urgency of addressing this issue is underscored by the growing scientific consensus on the detrimental impacts of climate change. Research such as that by Bakare et al. (2020) underscores the severe effects of climate change on vulnerable island nations in the South Pacific, emphasizing the threats of rising sea levels, extreme weather, and disruptions to food production. While SAARC countries may not face the same immediate threats, the long-term impacts of climate change, including altered weather patterns, water scarcity, and reduced agricultural productivity, pose significant risks to food security and overall well-being in the region.

Research by Dasgupta et al. (2014) highlights the imminent dangers of climate change in the Himalayan region, such as glacier melting, changing precipitation patterns, and more frequent extreme weather events. These changes upset agricultural production cycles and water resources, jeopardizing food security and livelihoods heavily reliant on agriculture. Rising sea levels pose a significant threat to low-lying coastal regions in SAARC countries, displacing communities and reducing available agricultural land. Therefore, mitigating livestock emissions and transitioning towards sustainable practices are not just environmental imperatives but also crucial measures for fostering strength against the adverse effects of climate change in the region.

This paper seeks to address the gap in empirical evidence on the contribution of livestock to CO_2 emissions in SAARC countries by analyzing panel data. In this context, this study aims to investigate the relationship between livestock production and CO_2 emissions, thereby assisting policymakers and stakeholders in formulating strategies that reconcile food security with climate change mitigation efforts. The results may also facilitate regional cooperation and the exchange of knowledge among SAARC countries, promoting sustainable livestock production practices and ensuring a more environmentally sustainable food system for future generations.

2. Literature Review

Livestock and Greenhouse Gas Emissions

Numerous studies emphasize the major role of livestock production in contributing to global greenhouse gas emissions. Studies by Gill et al. (2009) and Herrero et al. (2015) estimate that livestock directly emit around 9% of global GHGs, primarily methane (CH_4) and nitrous oxide (N_2O). This figure can rise to 18% when considering the entire production cycle, including feed production and transportation. Ruminant animals, such as cows and sheep, are major contributors due to their enteric fermentation process, which generates methane as a byproduct (Hristov et al., 2013). Agricultural activities also contribute to CO_2 emissions through land-use changes, deforestation, and the use of fossil fuels for machinery (Tubiello et al., 2013).

Beyond CO_2 emissions, livestock production impacts other environmental aspects. Appiah et al. (2018) and Balsalobre-Lorente (2019) link agricultural activities, including livestock production, to environmental concerns such as deforestation and energy consumption. These studies suggest that while economic growth might initially lead to increased emissions, a shift towards environmentally friendly practices can help decouple economic development from environmental degradation. The success of such a transition depends on adopting cleaner energy sources and sustainable agricultural technologies (Balsalobre-Lorente, 2019).

Measuring and Mitigating Livestock Emissions

Accurate measurement of livestock emissions is crucial for developing effective mitigation strategies. Reisinger and Ledgard (2013) explored the use of different metrics to convert various GHGs into CO_2 equivalents, facilitating easier comparison and analysis. However, alternative metrics, particularly for methane with its high short-term warming potential, can significantly alter the overall emissions profile (Persson et al., 2015; Reisinger and Clark, 2017).

Research efforts continue to identify and implement mitigation strategies to reduce livestock emissions. Improved grazing management practices, dietary changes for animals, and the use of feed additives are potential approaches (Thomton and Herrero (2010); Hristov et al., 2013). Nonetheless, economic feasibility, social and cultural considerations, and the need for international cooperation remain crucial factors for successful implementation (Herrero et al., 2015).

Regional Variations and Specific Studies

Studies have explored livestock GHG emissions across different regions and methodologies. Das et al. (2020) utilized the IPCC's Tier 1 approach to estimate livestock-related GHG emissions in Bangladesh from 2005 to 2018, projecting future emissions based on livestock population growth. Their findings indicated that enteric methane was the largest contributor to emissions, highlighting the need for targeted mitigation strategies.

Hao et al. (2022) examined China's livestock industry carbon emissions by province from 2000 to 2020, highlighting notable regional disparities. Emissions were positively linked to industrial structure, population, and income, while urbanization and agricultural mechanization reduced emissions. The study underscores the need for tailored regional strategies to effectively reduce emissions.

MacLeod et al. (2019) explored breeding strategies to reduce livestock emissions in the EU, finding that improving feed efficiency could reduce emissions by up to 0.5% annually. Challenges such as balancing efficiency with animal welfare and managing rebound effects were noted. Patra (2017) assessed the carbon footprint of livestock products in India, finding significant variations across states. The study emphasized the potential for reducing emissions through optimizing livestock population composition and adopting improved breeding practices.

The South Asian Context

The SAARC countries present a unique context for livestock production and its environmental impact. Studies by Yaqoob et al. (2022) highlight the importance of livestock for food security and rural livelihoods, particularly for smallholder farmers. However, the environmental impact of intensive livestock production practices often employed to meet rising demand is a growing concern. Rehman et al. (2021) provided insights into the impact of agricultural practices on CO_2 emissions in Pakistan, showcasing the potential positive and negative influences of various crops and land-use patterns.

Thomton and Herrero (2010) explored the potential for improved grazing management practices in tropical regions to reduce GHG emissions significantly. Given the prevalence of grazing systems in SAARC countries, adapting such practices could offer a cost-effective and regionally relevant mitigation strategy. Balsalobre-Lorente (2019) highlighted the positive impact of adopting cleaner energy sources and sustainable agricultural technologies on reducing emissions. Encouraging investment in renewable energy infrastructure and promoting climate-smart agricultural practices can be crucial steps towards a more sustainable livestock sector in SAARC countries.

However, challenges remain in implementing these solutions. The social and cultural significance of livestock in some South Asian communities needs to be considered when designing mitigation strategies (Herrero et al., 2015). Ensuring equitable access to knowledge, resources, and technology for smallholder farmers across the region is critical for the widespread adoption of sustainable practices. Collaborative efforts by governments, research institutions, and farmer organizations are essential to overcome these challenges and move towards a more sustainable and climate-friendly livestock sector in South Asia. Overall, understanding the specific emission profiles and challenges faced by SAARC countries will allow for the development of context-specific solutions that address their unique needs and opportunities.

In South Asia, the escalation of CO_2 emissions is intricately associated with the phenomena of rapid industrialization and urbanization, with notable contributions emanating from nations such as India and Pakistan (Das et al., 2020). Cattle, which serve as vital resources for dairy, meat, and draught power, are significant emitters of methane resulting from enteric fermentation, with regional analyses revealing substantial disparities in cattle populations (Gill et al., 2009; Herrero et al., 2015). The surging demand for poultry has culminated in heightened CO_2 emissions attributable to feed production and waste management practices (Tubiello et al., 2013). Goats, although less environmentally impactful than cattle, are indispensable to rural economies, and their associated emissions can be alleviated through the implementation of enhanced management strategies (Hristov et al., 2013). The Maldives, characterized by its limited landmass and constrained agricultural sector, lacks significant data regarding livestock production. As a result, information pertaining to livestock, including swine, remains either sparse or entirely absent for this particular nation (Das et al., 2020).

The existing corpus of academic literature reveals that the exploration of livestock's contribution in CO_2 emissions within the SAARC countries is significantly limited. Therefore, it is essential to address the shortcomings in empirical research concerning the contribution of livestock in CO_2 emissions within SAARC countries. Through a comprehensive examination of the relationship between livestock production and CO_2 emissions, this study aims to provide insights that will assist policymakers in developing strategies that harmonize food security with climate change mitigation. The anticipated findings are expected to enhance regional cooperation and the exchange of knowledge, thereby fostering sustainable practices and advancing a more environmentally sustainable food system within the SAARC nations.

3. Materials and Methods

The study is based on descriptive and analytical design (Khatri, 2022). The sources of data was employed from the dataset of World Bank, FAO, 2024. In this study, a panel data analysis was analyzed to investigate the contribution of livestock production to CO_2 emissions in SAARC countries. The panel data consisted of annual data points for each SAARC country from 1990 to 2020. The variables and units were presented in Table 1.

Table 1. Variables, Abbreviations, Units and Data Used in Research

Variable names	Symbols	Units	Sources
Carbon dioxide emission	CO_2	Kt.	World Bank,2024
Cattle Stock	cattle	Head	FAOSTAT, 2023
Chicken Stock	chicken	Head (in 1000)	FAOSTAT, 2023
Goats Stock	goats	Head	FAOSTAT, 2023

Data from SAARC countries were analyzed, but the Maldives has been excluded due to unavailable data. Additionally, some SAARC countries lack data on swine/pigs, so this category had also been excluded from the analysis. Data from SAARC countries is being analyzed, but the Maldives had been excluded due to data unavailability. Additionally, some SAARC countries lack data on swine/pigs, so this category had also been excluded from the analysis.

After calculating the descriptive statistics, we proceed with the panel unit root analysis, panel cointegration analysis, and ARDL to examine the causal relationship between cattle stock, chicken stock, goat stock, and CO_2 emissions.

Unit Root Test

This study utilized the Levin, Lin, and Chu (LLC) and Im, Pesaran, and Shin (IPS) unit root tests, as well as the ADF and PP-Fisher unit root tests, following methodologies proposed by Maddala and Wu (1999), Kao and Chiang (2000), Hadri (2000), Choi (2001), Levin et al. (2002), and Im et al. (2003).

Autoregressive Distributed Lag (ARDL) Approach

Models were commonly used for cointegration tests in the past studies, Engle-Granger (1987) and Johansen (1988) (Altıntaş, 2013). These models required variables to be stationary at I(1) and non-stationary at I(0) (Peseran et al., 2001). The ARDL bound test, however, accommodated non-stationary series at the same level (Pesaran and Shin, 1995; Pesaran et al., 2001), offering the benefit of testing cointegration without needing to assess the degree of integration. Key advantages of the ARDL approach included:

i. Its simplicity, which allowed for cointegration verification post-lag length determination, unlike Johansen and Juselius's (1990) methods.
ii. No need for preliminary unit root testing of variables, making it versatile even when variables were I(0) or I(1), but not I(2).
iii. Effectiveness with small or limited sample size.

4. Results

Descriptive Statistics

To minimize data variability across countries, the variables were transformed into their natural logarithms.

Table 2. Descriptive Statistics of Different Variables for SAARC Countries

	$LNCO_2$	LNCATTLE	LNCHICKENS	LNGOATS
Mean	9.696	15.823	10.396	15.542
Median	9.439	15.766	10.053	15.865
Maximum	14.715	19.136	14.182	18.832
Minimum	5.176	12.530	4.898	9.582
Std. Dev.	2.495	1.986	2.468	2.753
Skewness	0.280	0.032	-0.578	-0.728
Kurtosis	2.271	2.102	2.532	2.290
Observations	217	217	217	217

Table 2 summarized descriptive statistics for four variables ($LNCO_2$, LNCATTLE, LNCHICKENS, LNGOATS), each representing the natural logarithm of CO_2 emissions, cattle, chickens, and goats, respectively, with 217 observations each. The mean values were 9.696 ($LNCO_2$), 15.823 (LNCATTLE), 10.396 (LNCHICKENS), and 15.542 (LNGOATS). The median values were slightly lower, indicating some skewness. The maximum and minimum values showed the range of data, with standard deviations highlighting variability, highest in LNGOATS (2.753) and lowest in LNCATTLE (1.986). Skewness values showed that $LNCO_2$ and LNCATTLE were nearly symmetric, while LNCHICKENS and LNGOATS were negatively skewed. Kurtosis values indicated all distributions were slightly platykurtic, meaning they were less peaked than a normal distribution.

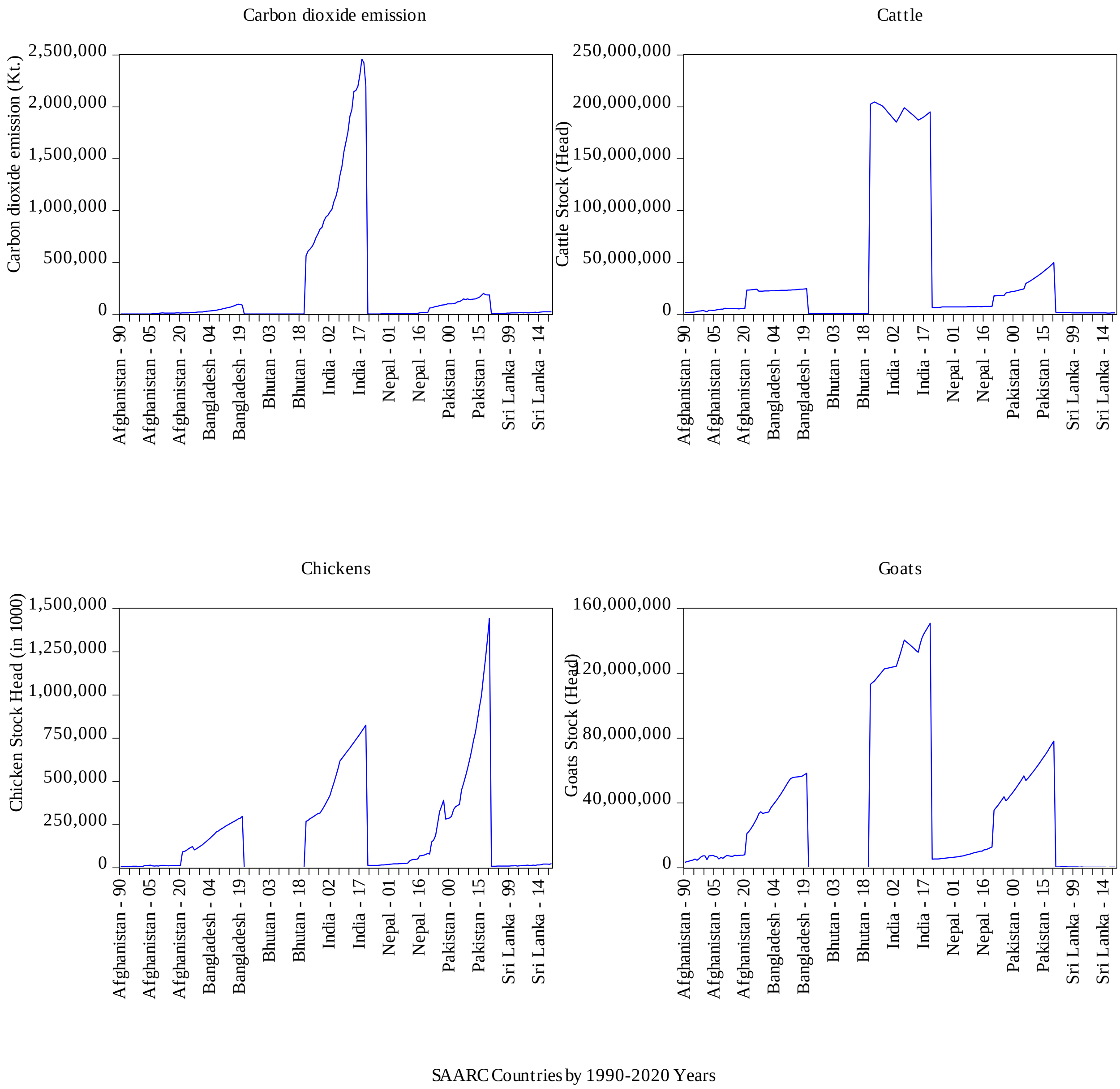

Fig.1. CO_2 Emission, Cattle Stock, Chickens Stock and Goats Stock of SAARC Countries by 1990-2020 Years

The x-axis represents SAARC countries, while the y-axis represents the variables: CO_2 emissions, cattle population, chicken population, and goat population, respectively. Each plot illustrates the trends of these variables across different countries. Data from SAARC countries, excluding the Maldives due to missing data, were analyzed. As swine/pig data were unavailable for some SAARC countries, this category was omitted. Fig. 1 presents trends in CO_2 emissions, cattle stock, chicken stock, and goat stock across the remaining SAARC countries from 1990 to 2020. This analysis aimed to identify patterns and relationships among these variables during the specified period.

Panel Unit Root Test Results (Individual Intercept)

The panel unit root test results with an individual intercept evaluate the stationarity of variables across a panel dataset, considering each series separately. These tests help determine whether the variables exhibit non-stationarity (unit root) or are stationary within the panel. The rejection of the null hypothesis indicates stationarity, which is essential for consistent and reliable panel data analysis. Table 3 presents the results of the unit root tests conducted on the variables with an individual intercept specification.

Table 3. Panel Unit Root Test Results (Individual Intercept)

Variables	Levin, Lin, Chu Test		Im, Peseran, Shin Test		ADF - Fisher Chi-square		PP - Fisher Chi-square	
	Level	1st diff.	Level	1st diff.	Level	1st diff.	Level	1st diff.
$Lnco_2$	-2..088**	-6.462*	1.318	-8.022*	7.426	85.781*	15.998	95.531*
Lncattle	-1.138	-8.553*	-0.608	-10.217*	19.183	112.197*	13.332	107.041*
Lnchickens	-0.758	-4.839*	3.056	-8.395*	6.393	92.421*	5.286	120.229*
Lngoats	1.869	-7.439*	2.031	-8.268*	11.103	92.171*	17.561	119.785*

(* denotes 1% and ** denotes 5% significant level)

The unit root tests for the variables $Lnco_2$, Lncattle, Lnchickens, and Lngoats indicate that all series are non-stationary at their levels but become stationary after first differencing. This conclusion is supported by the Levin, Lin, Chu test, the Im, Pesaran, Shin test, and both the ADF and PP Fisher Chi-square tests, as the test statistics (marked with * and ** for 1% and 5% significance levels, respectively) show non-stationarity at levels and significant stationarity after differencing. Thus, for reliable econometric analysis, these variables should be used in their differenced form to avoid issues of false regression.

VAR Lag Order Selection Criteria

The selection of the appropriate lag length in a Vector Autoregression (VAR) model is essential for achieving precise model specification and robust empirical results. The VAR Lag Order Selection Criteria table provides key statistical metrics, including the Log-Likelihood (LogL), Likelihood Ratio (LR), Final Prediction Error (FPE), Akaike Information Criterion (AIC), Schwarz Criterion (SC), and Hannan-Quinn Criterion (HQ), to inform this decision. The optimal lag length, usually identified by the lowest criterion value, is marked with an asterisk (*), directing researchers to the most appropriate model configuration.

Table 4. VAR Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-1033.629	NA	0.690	10.980	11.049	11.008
1	769.726	3511.293	4.21e-09	-7.934	-7.591*	-7.795*
2	780.764	21.025	4.44e-09	-7.881	-7.264	-7.631
3	803.413	42.183*	4.14e-09*	-7.951*	-7.060	-7.590
4	816.777	24.324	4.26e-09	-7.924	-6.757	-7.451

The VAR Lag Order Selection Criteria table determines the ideal lag length for a Vector Autoregression (VAR) model by evaluating log-likelihood, likelihood ratio, final prediction error, and various information criteria including Akaike, Schwarz, and Hannan-Quinn. The results suggest that Lag 3 is generally the best choice, with the highest LogL (803.413), the lowest FPE (4.14e-09), and the lowest AIC (-7.951). However, Lag 1 also performs well, featuring the lowest SC (-7.591) and HQ (-7.795) values, making it another viable option. In summary, while Lag 3 is optimal by most criteria, Lag 1 is notable for its SC and HQ values.

Panel Cointegration Test

The Kao Residual cointegration test assesses the presence of a long-run equilibrium relationship between variables in a panel data context by examining the residuals from a spurious regression. The Johansen Fisher panel cointegration test, on the other hand, extends the Johansen cointegration methodology to panel data, allowing for multiple cointegrating relationships and providing more robust and comprehensive results by combining individual cross-sectional tests using Fisher's method.

Table 5. Panel Cointegration Test Results

Kao Residual cointegration test
Series: LNCO_2 LNCATTLE LNCHICKENS LNGOATS
Null Hypothesis: No cointegration

Test method	t-Statistic	Prob.
ADF	-1.646	0.049
Residual variance	0.015	
HAC variance	0.022	

Johansen Fisher panel cointegration test
Unrestricted cointegration rank test (Trace and Maximum Eigenvalue)

Hypothesized No. of CE(s)	Fisher Stat.* (from trace test)	Prob.	Fisher Stat.* (from max-eigen test)	Prob.
None	250.8	0.000	167.4	0.000
At most 1	138.7	0.000	97.50	0.000
At most 2	63.72	0.000	50.48	0.000
At most 3	37.81	0.001	37.81	0.001

* Probabilities are computed using asymptotic Chi-square distribution
Individual cross-section results

Cross Section	Trace Test Statistics	Prob.**	Max-Eign Test Statistics	Prob.**
The hypothesis of no cointegration				
Afghanistan	86.456	0.000	37.269	0.002
Bangladesh	112.917	0.000	53.629	0.000
Bhutan	80.784	0.000	46.924	0.000
India	110.566	0.000	52.884	0.000
Nepal	117.694	0.000	63.204	0.000
Pakistan	154.580	0.000	83.902	0.000
Sri Lanka	76.027	0.000	39.277	0.001

The Kao Residual cointegration test for the series $LNCO_2$, LNCATTLE, LNCHICKENS, and LNGOATS rejects the null hypothesis of no cointegration, as indicated by the ADF t-statistic of -1.646 with a p-value of 0.049, suggesting a long-run equilibrium relationship among the variables. The ADF t-statistic is negative, which is typical in unit root and cointegration tests. It suggests that the residuals from the cointegration equation are less likely to have a unit root, implying that the series may be cointegrated. The Johansen Fisher Panel cointegration Test, both for trace and maximum eigenvalue, strongly rejects the null hypothesis of no cointegration across multiple ranks, with highly significant Fisher statistics (e.g., 250.8 and 167.4 for no cointegration, both with p-values of 0.000). This test also provides individual cross-section results, confirming significant cointegration for each country analyzed (e.g., Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka), further substantiating the presence of cointegrating relationships within the panel data.

ARDL Bound Test

The ARDL Bound Test assesses the existence of a level relationship between variables in an autoregressive distributed lag (ARDL) model by comparing the calculated F-statistic against critical value bounds. If the F-statistic exceeds the upper bound, it indicates cointegration among the variables; if it falls below the lower bound, no cointegration is present, while values within the bounds result in an inconclusive test.

Table 6. ARDL Bound Test Results; Dependent Variable: D($LNCO_2$); Selected Model: ARDL (1, 3, 3, 3)

	Coefficient	Std. Error	t-Statistic	Prob.*
Variable	Long Run Equation			
LNCATTLE	2.948	0.212	13.930	0.000
LNCHICKENS	2.369	0.134	17.635	0.000
LNGOATS	-5.594	0.590	-9.486	0.000
	Short Run Equation			
COINTEQ01	-0.083	0.053	-1.576	0.117
D(LNCATTLE)	0.702	0.497	1.413	0.160
D(LNCATTLE(-1))	0.276	0.399	0.693	0.490
D(LNCATTLE(-2))	-1.129	0.413	-2.733	0.007
D(LNCHICKENS)	-0.308	0.175	-1.760	0.081
D(LNCHICKENS(-1))	-0.033	0.111	-0.302	0.763
D(LNCHICKENS(-2))	0.003	0.246	0.013	0.990
D(LNGOATS)	0.188	0.280	0.671	0.503
D(LNGOATS(-1))	0.356	0.303	1.175	0.242
D(LNGOATS(-2))	0.883	0.726	1.217	0.226
C	2.596	1.579	1.644	0.102
Mean dependent var	0.059	S.D. dependent var		0.116
S.E. of regression	0.095	Akaike info criterion		-1.745
Sum squared resid	1.236	Schwarz criterion		-0.499
Log-likelihood	269.332	Hannan-Quinn criteria.		-1.242

Table 6 presents the results of an Autoregressive Distributed Lag (ARDL) model, specifying the dependent variable as D(LNCO_2) and the selected model as ARDL (1, 3, 3, 3). It comprises both long-run and short-run equations. In the long-run equation, coefficients represent the relationship between LNCO_2 and the explanatory variables. Notably, LNCATTLE and LNCHICKENS demonstrate positive and statistically significant associations with LNCO_2, suggesting that higher cattle and chicken stocks correlate with increased CO_2 emissions. The strong long-run relationship between livestock and CO_2 emissions underscores the need for targeted environmental policies in the agricultural sector. For instance, reducing cattle numbers or improving farming practices could be effective strategies for mitigating long-term CO_2 emissions. Conversely, the negative and significant coefficient for LNGOATS suggests that goat farming may contribute to a reduction in CO_2 emissions, possibly due to more sustainable agricultural practices. The negative long-run coefficient for goats suggests that promoting goat farming might be a more sustainable option in certain contexts, potentially reducing the overall carbon footprint of livestock farming.

In the short-run equation, the coefficients denote the impact of changes in the explanatory variables on LNCO_2 over time. The error correction term is negative, though statistically insignificant, indicating a slow adjustment process towards long-run equilibrium. The dynamics of livestock variables show mixed effects, with some lagged coefficients reaching significance, particularly for LNCATTLE, but overall suggesting that short-term fluctuations in livestock numbers do not consistently affect CO_2 emissions. The weak and mixed short-run dynamics indicate that immediate policy interventions might not have a significant impact on CO_2 emissions.

Long-term strategies that focus on structural changes in livestock management might be more effective. These findings underscore the importance of long-term policy interventions targeting livestock management to effectively mitigate CO_2 emissions, while highlighting the potential role of goat farming in sustainable agricultural practices. The results offer valuable insights into the dynamics of CO_2 emissions in livestock stocks, aiding in the understanding of their contribution to global warming. This ARDL model provides valuable insights into the relationship between livestock and CO_2 emissions, highlighting the importance of long-term agricultural planning in addressing environmental concerns.

Cross Section Short-run Cointegration Coefficients

Cointegration coefficients highlight how different nations experience varying effects, with some exhibiting significant reductions and others showing increases in emissions. This variability underscores the need for tailored approaches in environmental policy to address the unique conditions and impacts in each country. Table 7 presents the country-specific cointegration coefficients for the impact of a given variable on CO_2 emissions.

Table 7. Cross Section Short-run Cointegration Coefficients

Country	Coefficient	Std. Error	t-Statistic	Prob. *
Afghanistan	-0.325	0.002	-179.569	0.000
Bangladesh	-0.020	0.000	-72.706	0.000
Bhutan	0.034	0.001	30.718	0.000
India	-0.241	0.002	-122.280	0.000
Nepal	-0.025	0.004	-6.281	0.008
Pakistan	0.011	6.28E-05	174.782	0.000
Sri Lanka	-0.018	0.000	-59.001	0.000

Table 7 presents the cointegration coefficients, standard errors, t-statistics, and p-values for the impact of a variable on CO_2 emissions across SAARC countries. Each country's data provides insights into how changes in the variable influence CO_2 emissions. Across the countries analyzed, the variable shows a significant impact on CO_2 emissions, with varying magnitudes and directions. Afghanistan, India, and Sri Lanka demonstrate strong negative relationships, suggesting substantial reductions in CO_2 emissions. Bhutan and Pakistan show positive relationships, indicating increases in CO_2 emissions. Bangladesh and Nepal exhibit minor effects, with Nepal showing a less pronounced impact. These variations underscore the importance of considering country-specific contexts in environmental policy and economic analysis.

The results provide insights for crafting targeted environmental policies. Countries with strong negative coefficients, like Afghanistan and India, could enhance policies promoting variables linked to emissions reductions. Conversely, nations with positive coefficients, such as Bhutan and Pakistan, may need strategies to mitigate increased emissions from growth. Tailored approaches and international collaboration are essential for effectively managing CO_2 emissions and balancing economic development with environmental sustainability.

Model Selection Graph

The ARDL Model Selection Graph illustrates the optimal lag length for each variable based on various selection criteria, including the Akaike Information Criterion (AIC). The graph helps identify the lag structure that minimizes the AIC, guiding researchers to choose the most appropriate model specification. This approach ensures a balance between model fit and complexity, enhancing the reliability of the analysis. Fig. 2 presents the optimal lag length selection for each variable in the ARDL model, determined by the Akaike Information Criterion (AIC).

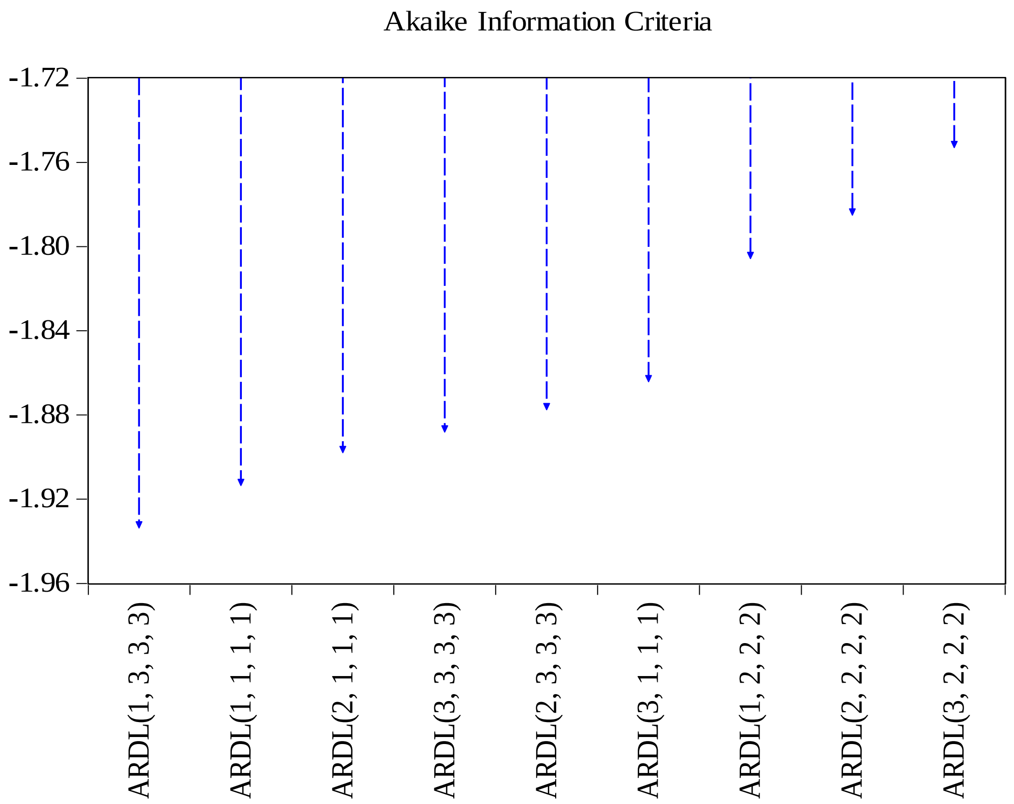

Fig.2. Model Selection Graph of Akaike Information Criterion

In Fig. 2, the X-axis represents the lag lengths considered for each variable in the ARDL model, while the Y-axis shows the corresponding values of the Akaike Information Criterion (AIC). The lowest Akaike Information Criterion (AIC) indicates that the ARDL (1, 3, 3, 3) model is the best fit among the evaluated models. Therefore, this model is selected because it minimizes the AIC, suggesting it has the optimal balance of goodness of fit and model complexity.

5. Discussion

The analysis presented offers crucial insights into the dynamics between livestock production and CO_2 emissions within the SAARC countries, revealing important patterns and implications for environmental and agricultural policies. The study's findings underscore the complexity of managing livestock-related greenhouse gas emissions in a region where agricultural practices and livestock rearing are integral to economic and social systems. Analysis of panel data from 1990 to 2020 reveals significant variability in CO_2 emissions from livestock production across SAARC countries. Descriptive statistics and graphical data illustrate diverse patterns in CO_2 emissions and livestock stocks, highlighting regional and temporal differences. Unit root tests show that CO_2 emissions and livestock stocks are non-stationary at their levels but become stationary after first differencing. Cointegration tests confirm long-run equilibrium relationships among these variables, indicating a long-term link between livestock production and CO_2 emissions. The ARDL Bound Test results indicate that cattle and chicken stocks positively affect CO_2 emissions, while goat stocks show a negative relationship. The short-run analysis reveals mixed results, suggesting that short-term dynamics may be influenced by other factors not captured in this model.

In examining the relationship between livestock production and CO_2 emissions in SAARC countries, multiple studies have provided valuable insights. Dogan and Sacli (2019) found that the indirect effects of livestock activity can be effective in CO_2 emissions as much as livestock numbers. These findings align with Patra (2017) who also observed regional disparities in livestock emissions in India, emphasizing the importance of livestock population composition. Hao et al. (2022) further confirmed these disparities in China, attributing emissions variability to factors such as industrial structure and income levels. In contrast, Das et al. (2020) utilized the IPCC's Tier 1 approach to estimate livestock-related emissions in Bangladesh, stressing the need for tailored mitigation strategies. Herrero et al. (2015) and Hristov et al. (2013) also supported these conclusions, with both studies pointing to the potential for emissions reduction through improved livestock management practices and the adoption of cleaner energy sources in agricultural activities. To address emissions, strategies should focus on sustainable livestock management, technological innovations, regional collaboration, and policy integration. Mitigation efforts must consider economic and social impacts on communities reliant on livestock particularly in the diverse context of SAARC countries.

Contrary to the findings, Steinfeld and Wassenaar (2007) argued that livestock's contribution to greenhouse gas emissions may be overstated due to methodological differences. Additionally, Herrero et al. (2014) suggest that effective livestock management can mitigate emissions more than our results indicate. Zervas and Tsiplakou (2011) found that goat farming still posed significant emission challenges, contrary to our conclusions about its sustainability.

The current study faces several limitations. First, the use of aggregated data from 1990 to 2020 may obscure regional or temporal variations, potentially affecting the accuracy of findings. Additionally, excluding other relevant variables could lead to incomplete insights into the relationship between CO_2 emissions and livestock production. The ARDL model, while useful, may not capture all short-term interactions or complex dynamics between the variables. Furthermore, the findings may not be universally applicable, as conditions and practices vary significantly across different regions. Finally, the proposed mitigation strategies might differ in effectiveness and feasibility depending on the specific contexts of the countries within the SAARC region.

6. Conclusion

This research provides a comprehensive analysis of livestock production and its associated CO_2 emissions within SAARC countries, emphasizing the substantial association between existing livestock management practices and greenhouse gas emissions. The results of the ARDL Bound Test indicate that cattle and chicken stocks have positively contributed CO_2 emissions, while goat stocks have showed a negative relationship. The findings underscore the urgent need for targeted interventions to address these emissions as a critical component of effective climate change mitigation strategies. It is evident that without implementing region-specific approaches that consider the distinct environmental and socio-economic contexts of SAARC countries, achieving meaningful reductions in emissions will be challenging.

Moreover, the research strongly advocates for the adoption of improved livestock management practices, including dietary modifications and enhanced manure management, as viable solutions to significantly reduce emissions. The effectiveness of these measures is contingent upon the collaboration of governments, research institutions, and local communities. The research concludes by recommending that SAARC countries prioritize the development and execution of tailored, sustainable livestock practices to not only decrease CO_2 emissions but also enhance the region's overall climate resilience.

Conflict of interest statement

The authors declare no competing interests.

Authors contribution statement

Conceptualization: BBK, OP. Literature review: OP, PA. Methodology: BBK, OP. Model selection: OP, BBK. Data analysis & software use: OP, PA. Writing original draft: OP, PA, Editing and finalizing manuscript: BBK

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