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An Econometric Analysis of Influence of Livestock Production on Greenhouse Gas Emission in South Africa

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ABSTRACT

The aim of this article is to analyse the long-term impact of different livestock production and on greenhouse gas emissions in South Africa. Using data for the period 1981-2022, the study applied the ARDL techniques to determine the cointegration relationships and the long-run effect of the variables of interest in four models on the GHG emission. The empirical findings reveal that beef and buffalo meat production significantly reduce CH_4 emissions but increase N_2O emission, poultry meat production significantly reduces CO_2 emission but significantly increase methane and nitrogen oxide emissions, pig meat production was found to reduce methane and nitrogen oxide emission by 0.11% and 0.98%, respectively, but have increasing effect of 0.29% on CO_2. The finding obtained shows mixed results of impact of different livestock production on GHGs emission that in the long-run in South Africa. These mixed results underscore the complexity of achieving sustainable livestock production. Similarly, the variability in the impact of different types of meat production on GHG emissions indicates that a one-size-fits-all approach to mitigating emissions in the livestock sector may not be effective.

Keywords: Agriculture, Livestock Production, Greenhouse Gas Emissions, South Africa
JEL Classifications: Q15. Q53

1. INTRODUCTION

The reality of a changing and unfavourable climatic condition is agreed by government of nations, development partners and researchers to be having several interwoven causes and impacts. This fact resonates with the concerns regarding the environmental component of sustainable development. Sustainable development based on the most quoted definition by World Commission on Environment and Development [WCED], (1987) is a development that meet the needs of the present without compromising the ability of future generations to meet their own needs. The continued pursuit of sustainable development over the years made world leaders and development partners come up with various unified development goals such as the 2015 MDGs and 2030 SDGs. The most recent development goals called the SDGs or Global Goals which came to effect in January 2016 are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity (UNDP, 2019).

The SDG have 17 goals that were agreed to be achieved by the year 2030. One of these goals is goal number 12 which aims to "ensure sustainable consumption and production patterns". Sustainable economic activities (consumption and production patterns) are a prerequisite for the transition to a green economy which is also imperative for sustainable development (Figure 1). Green economy is an economy that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological disturbance (UNDP, 2011). The transition to sustainable consumption and production of goods and services is necessary to reduce the negative impact of these activities on the climate, the immediate environment and people's health and wellbeing.

One of the several causes of environmental pollution and increasing environmental risk is greenhouse gas emission. Greenhouse gases (GHGs) are composed of methane (CH_4), carbon dioxide (CO_2), ozone (O_3), water vapour (H_2O), and nitrous oxide (N_2O) (Tarazkar et al., 2020). Nevertheless, CO_2, CH_4, and N_2O are the most abundant gases with high global warming potentials (Liu et al. 2020). GHGs emitting activities have been identified to be from several economic sectors including energy, transport, industry (manufacturing, mining and construction), agriculture, and waste. In the agricultural sector, Crippa et al., (2021) noted that the activities that encompassed the food system including crop and livestock production, harvesting, transporting, processing, packaging, distribution and cooking, and the disposal of wastes all contribute to GHGs emissions and energy use. Nabuurs et al., (2022) noted that Agriculture, Forestry and Other Land Use (AFOLU) accounted for 13%-21% of global total anthropogenic greenhouse gas (GHG) emissions in the period between 2010 and 2019. Estimation from Crippa et al., (2021) further revealed that the food system contributes about 34% to global GHG emission, out of which 71% of global GHG emissions from the food system was associated with the land-based activities.

Livestock production is an integral element of the agriculture sector, it supports the livelihood of more than 1 billion people across the globe, however, it is also one of the major contributors to the changing climate through its emission of GHGs of CH_4, CO_2, and N_2O (Sejian et al., 2016; FAO, 2022). Methane is a gas that has about 28 times the higher effect on global warming than carbon dioxide, nitrous oxide on the other hand is a molecule with a global

Figure 1: A schematic representation of GHGs, Food production and sustainable development

warming potential 265 times higher than carbon dioxide (Grossi et al., 2019). FAO (2022) estimated that emissions from global livestock agrifood systems (which include cattle, buffaloes, sheep, goats, pigs and chickens) are responsible for 6.2 gigatonnes of carbon dioxide equivalent (CO_2 eq.) emissions (i.e., approximately 12% of all anthropogenic GHG emissions) based on the reference year 2015. 54% of all livestock emissions are attributed to CH_4, while CO_2, and N_2O represent smaller proportions, accounting for 31% and 15%, respectively (FAO, 2022). Likewise, the level of emission contribution differs within the livestock subsector and location as seen in Table 1. For instance, the emission contribution of cattle (that is beef cattle and dairy cattle) is much higher than the emission contribution of pigs, poultry, buffaloes, and small ruminants collectively.

Without a doubt, climate change and the consequent global warming could be tackled through the livestock subsector of the agricultural sector. However, the increase in human demand for livestock products has increased rapidly during the past few decades largely due to dietary transition and population growth as noted by Dangal et al., (2017), raises concern about the extent to which the livestock subsector could offer a solution to the global climate change problem, especially from an individual country perspective where there is the heterogeneity of dietary transition and population growth features. Therefore, this study attempts to address one question should the level of meat production in South Africa be a thing to worry about? The specific objective of the study is to examine the long-and short-run period effect of meat production on GHG emission in South Africa.

2. LITERATURE REVIEW

The empirical literature on the relationship between climate change and agriculture has witnessed significant evolution, reflecting a growing awareness of agriculture's role in greenhouse gas (GHG) emissions. A number of studies have explored the agricultural impact of GHG emissions (Kumar et al., 2021; Chandio et al., 2020a; Warsame et al., 2021; Janjua et al., 2014; Ali et al., 2017), while others have focused on how agricultural activities contribute to GHG emissions (Yurtkuran, 2021; Doğan, 2019; Balsalobre-

Table 1: Global emissions from livestock

Global Emissions from Livestock in 2015 [CO_2 Gt]						
Region	Total emission	% of total GHG				
World	6.2	12				
Africa	655.8	1.3				
Americas	2.1	4.1				
Asia	2.6	4.2				
Europe	736.5	1.4				
Oceania	129.5	0.25				
Global Emission from Livestock in 2015: Emission by Species (Mt)						
Region	**Cattle**	**Buffalo**	**Goat**	**Sheep**	**Chicken**	**Pig**
World	3844.04	514.23	224.53	211.07	576.63	852.04
Africa	481.61	10.41	70.71	54.34	24.37	14.34
Americas	1726.70	4.46	8.34	17.35	171.10	141.64
Asia	1054.45	498.02	132.81	91.97	315.15	538.73
Europe	481.92	1.32	11.84	27.99	61.56	151.98
Oceania	99.38	0.01	0.84	19.41	4.44	5.42

Source: FAO (2022) Global Livestock Environmental Assessment Model [GLEAM] 3 Dashboard. https://foodandagricultureorganization.shinyapps.io/GLEAMV3_Public/

Lorente et al., 2022; Haider et al., 2021; Khan, 2020; Eyuboglu and Uzar, 2020; Ghosh, 2018). However, much of this research is broad and tends to aggregate agricultural emissions rather than breaking down the specific impacts of individual agricultural activities. This presents a crucial gap in the literature that demands more attention to how specific farming practices, particularly livestock production (or meat production), affect GHG emissions.

For instance, Shafiullah et al. (2021) present intriguing insights into the nuanced relationship between meat consumption and GHG emissions in the United States. Using dynamic ordinary least squares (DOLS) and Toda-Yamamoto Granger causality techniques, the authors uncovered a U-shaped relationship between chicken and pork consumption and carbon emissions but found an inverted U-shaped pattern with methane and nitrous oxide. This finding, while valuable, raises a critical question: Why exclude beef from the analysis, given its well-documented environmental impact? Beef consumption is notorious for its outsized role in GHG emissions, and its omission potentially limits the study's broader applicability. A similar study by Raihan (2023b) in the United States confirmed that increasing meat consumption leads to higher GHG emissions, although the study could be expanded to include different livestock production practices. Similarly, Leitão and Balogh (2020) examined the effects of agricultural production on CO_2 emissions in Portugal over an extensive period (1960-2015), finding that while crop production reduces CO_2 emissions, livestock production and land use exacerbate them. This study is valuable for its long timeframe, yet it falls short in considering other significant GHGs like methane and nitrous oxide, which are closely linked to livestock production. Furthermore, the study's focus on one country, though insightful, invites further exploration into whether similar dynamics hold across other agricultural economies.

A more global perspective comes from Balogh (2020), who studied agricultural determinants of climate change across 159 countries. His work highlights the substantial role of livestock in driving CO_2 emissions, a finding echoed in other studies. However, the broad scope of study's analysis risks glossing over important regional variations in agricultural practices and GHG impacts. For instance, livestock production in developing nations might present unique challenges and opportunities compared to more industrialized countries, and these differences deserve greater attention. Rehman et al. (2021) also addressed the impact of agriculture on CO_2 emissions, focusing on Pakistan. Their use of vector autoregressive models and Granger causality techniques revealed that forestry, crop, and livestock production negatively affect CO_2 emissions in the long run, with positive but insignificant short-term effects. This presents a paradox on why agricultural activities reduce emissions over the long term but show no short-term significance? The complexity of the long-run dynamics, potentially due to lagged effects or gradual shifts in agricultural practices, calls for a more detailed investigation to unpack these counterintuitive findings.

On a broader scale, Appiah et al. (2018) explored the relationship between agricultural production and CO_2 emissions in emerging economies, showing that growth in livestock and crop production significantly increases emissions. While this study is pivotal in linking economic development to environmental degradation, yet it risks oversimplifying the diverse agricultural practices within countries like Brazil, India, and South Africa. Ayyildiz and Erdal, (2021) expanded on this by examining 184 countries and categorizing them by income levels. The findings from the study suggest that that animal production raises emissions across all income groups except low-income countries. The significant differences between income groups underscore the importance of income-sensitive agricultural policies, as wealthier nations contribute disproportionately to GHG emissions. This study importantly hints at the potential of low-income countries to adopt more sustainable agricultural practices, an area that warrants further exploration, particularly in light of global food security concerns.

Other studies, such as those by Ullah et al. (2018) and Sarkodie and Owusu (2017), focus on country-specific analyses, revealing that both crop and livestock production contribute significantly to CO_2 emissions. These studies provide essential regional insights, but the generalizability of their findings is limited by the specificity of their geographic contexts. Ullah et al.'s (2018) conclusion that livestock production has a greater long-run impact on CO_2 emissions in Pakistan, for example, contrasts with findings from other regions, suggesting the need for more comparative studies that examine how climate and regional agricultural practices interact. These findings align with those of Ali and Anufriev (2020), which also highlighted the environmental impact of livestock and crop production in Ghana.

Hongdou et al. (2018) investigated the impact of livestock production on CO_2 emissions in India, finding a positive but statistically insignificant effect, which is consistent with the findings of Ali et al. (2021). Vetter et al. (2017) highlighted that agriculture is the primary source of global GHG emissions, with livestock and rice production contributing more significantly to emissions than cereal production. This study underscores the need for balancing food security with the minimization of GHG emissions. Chandio et al. (2020b) confirmed that livestock production in China has a positive impact on CO_2 emissions in both the short and long run, although the effect is only significant in the short term. The study's findings suggest a need for policy interventions to reduce carbon footprints in the livestock sector.

Ridzuan et al. (2020) analyzed the effects of agricultural subsectors on CO_2 emissions in Malaysia, revealing that while crops and fisheries reduce CO_2 emissions in the long run, livestock production has no significant impact. Raihan (2023a) investigated the relationship between meat consumption and GHG emissions in Argentina from 1990 to 2020, finding that a 1% increase in meat consumption results in a 0.91% rise in GHG emissions in the long run.

The reviewed studies collectively highlight the significant role of agriculture, particularly livestock production, in contributing to greenhouse gas emissions. However, several studies could benefit from including a broader range of greenhouse gases, such as methane and nitrous oxide as it is observed that or noted that the aspect of non-CO_2 GHGs, such as methane and nitrous oxide, is omitted in several studies. Additionally, while the global and cross-country studies offer valuable insights, they often lack attention to regional specificities and diverse agricultural practices that can vary widely within and between countries. This presents a clear research gap-future studies should expand their scope to encompass the full spectrum of GHG emissions from agriculture, offering a more comprehensive understanding of the sector's environmental impact.

3. METHODOLOGY

3.1. Model Specification and Description of Variables

This study adopted a multivariate model specification following Shafiullah et al., (2021), Raihan (2023), and Raihan (2023) in specifying the relationship between the variables of interest. The implicit representation of the relationship is as follows.

Green House Gases=f (Livestock, Income, Energy Use) (1)

In line with similar studies, Green House Gases emission is the dependent variable, and it is proxied by CO_2, N_2O (CO_2 eq.) and CH_4 emissions in this study. All the proxies are of indicators/measures for/of environmental quality. Livestock in this study is the process of breeding and raising animal for meat production. It is measured in tonnes as the amount of meat produced. The effect of livestock production has been extensively explained in the introductory part of this study. In this study the livestock production considered are beef and buffalo, poultry, sheep and goat, and pig. It is represented as LVS1, LVS2, LVS3, LVS4. Income often influence emission through consumption channel. As income rises, people generally consume more goods and services but meeting the demand increase comes along with increasing energy use and resource extraction which all together contribute to emissions. Similarly, increased income stimulates environmental emission through increase in the purchase of more energy-requiring and intensive goods and services by people (Lin et al., 2015). For instance, individuals may purchase more cars or travel more frequently by air and use more electricity when their income increases. All these increase various forms of GHG emissions. Hence, it is expected that increase in income will lead to increase in emission in this study. Income is proxy by per capita GDP. On energy use variable**,** higher levels of economic activity tend to go together with additional energy use and consumption of natural resources (Lin et al., 2016). Because non-renewable energy sources still account for the majority of South Africa's energy mix, energy consumption remains closely related to greenhouse gas emissions and hence contributes to environmental degradation.

Since four livestock's' are considered in this study, the earlier stated equation (1) is therefore extended.

GHG=f (LVS1, LVS2, LVS3, LVS4, Income, Energy Use) (2)

The explicit mathematical expression of the equation 2 is stated as follows:

$$GHG_t=\alpha_1+\alpha_2 LVS1_t+\alpha_3 LVS2_t+\alpha_4 LVS3_t+\alpha_5 LVS4_t +\alpha_6 GDPPC_t+\alpha_7 EU_t+e_t \quad (3)$$

This empirical study utilized time series data for the period 1981-2022. Data for CO_2 emission and GDP per capita were extracted from the World Development Indicators website whereas data for all the livestock were obtained from Our World in Data website.

3.2. Analytical Techniques

Descriptive and inferential statistics (unit root test, ARDL, post estimation tests) were employed in the study to know the characteristics of the series, examine the existing relationships, estimate effects, and validate the estimated model. ARDL Bound test is used to establish if there exists any form of long-run cointegration relationship among variables in the model that is being estimated. Besides, unlike other cointegration relationship test techniques, ARDL provides a platform that enables estimation irrespective of whether the series are integrated of the same other or not, only if the order of integration is not more that I(1). Similarly, with ARDL techniques the effects and size of the effect of independent variables on the dependent variable in both short and long-run periods can be at once computed and examined (Demirhan, 2020; Pesaran et al., 2001; Ewetan et al., 2020).

4. RESULTS AND DISCUSSION

The initial summary statistics of the variables are important in describing the characteristics of the raw data. Table 2 reports the descriptive statistics for the variables to utilize in this study. Results show that all variables are normally distributed as shown by Jarque-Bera statistics.

4.1. Unit Root Test

To examine the unit root properties of the variables, ADF unit root test techniques was applied. Table 3 presenting the results of the ADF unit root tests indicate that the null hypothesis of non-stationarity cannot be rejected at the level form for each of the variables. This suggest that all the variables have a unit root problem at levels. However, after taking a first differencing of the variables, there is an adequate reason to reject the null hypothesis of non-stationarity, as required. Hence, it is concluded that all the variables are stationary and are integrated at I(1).

4.2. Lag Selection and Cointegration

The Schwarz information criterion (SC) was employed to select the optimal model needed in estimating the long-run relationship between the variables in the model. The optimal lag model selected using the Schwarz Information Criterion ARDL (4,1,4,4,4,4,4), ARDL (4,2,4,4,4,4,4), ARDL (4,4,4,4,3,4,3), ARDL (3,4,4,4,4,3,4) for model 1, model 2, model 3, and model 4, respectively. ARDL Cointegration test was employed to ascertain the existence or otherwise of long-run equilibrium relationship among variables in each of the greenhouse gas emission models. The result of the ARDL bounds test for the cointegration relationship is presented in Table 4. Evidence from Table 3 shows that the F-statistic for each of the models (model 1: 5.81; model 2: 6.63; model 3: 9.87, and model 4: 11.98) exceed the critical value of the upper bound at all levels of significance, thereby confirming the existence of cointegration relationship between the dependent and independent variables in all the model under consideration, respectively.

Table 2: Summary statistics of variables

Variables	Mean	Median	Maximum	Minimum	Obs.
TGHG	514 726 218,81	521 052 290,00	625 110 100,00	357 298 720,00	42
CO_2	432 092 126,19	435 622 650,00	527 482 370,00	313 118 750,00	42
CH_4	83 400 839,05	86 850 765,00	96 453 990,00	58 588 800,00	42
N_2O	19 603 473,48	19 931 925,00	22 271 862,00	16 445 793,00	42
Beef (LVS1)	746 396,34	682 000,00	1 089 686,00	480 000,00	42
Poultry (LVS2)	984 162,64	901 361,00	1 958 344,10	247 104,75	42
Sheep and Goat (LVS3)	155 044,43	163 750,00	194 670,00	105 550,00	42
Pig (LVS4)	168 071,14	130 600,00	351 560,00	95 700,00	42
GDPPC	5 332,10	5 250,16	6 263,10	4 269,70	42
Energy_Use	1 206,95	1 188,46	1 481,87	751,93	42

Table 3: Unit root test result

Variables	ADF		Decision
	Level	First Difference	
lnTGHG	−1.7413	−7.2208*	I (1)
lnCO_2	−2.2769	−7.2237*	I (1)
lnMethane	−0.2671	−7.7143*	I (1)
lnNitrogen Oxide	−1.7433	−6.2072*	I (1)
lnLVS1	−3.1343	−8.8183*	I (1)
lnLVS2	−2.0381	−5.6131*	I (1)
lnLVS3	−1.7646	−5.5290*	I (1)
lnLVS4	−1.0164	−6.3986*	I (1)
lnGDPPC	−2.2514	−4.2850*	I (1)
lnEnergy_Use	−1.5767	−8.6503*	I (1)

4.3. Long-run Estimation

Following the establishment of a cointegration relationship among the variables for each of the emission models considered in this study, an estimation of the relative effect and magnitude of the effect of each dependent variable on the dependent variable in the long-term was conducted using the ARDL technique. Table 5 presents the results of the long-run estimates of emission equations.

4.4. Livestock (Meat) Production and Emissions

The result in column 1 of Table 5, indicate that an increase in beef and buffalo production cannot significantly reduce total GHG emission. However, the results regarding specific emissions show that beef and buffalo meat production significantly reduce CH_4 emissions but increase N_2O emission. The coefficient of −0.11 for beef and buffalo meat production which is statistically significant at the 1% level, suggests a 0.11% reduction effect on methane emissions if beef and buffalo meat production increases by 1% but same production increase would lead to about 3.17% increase in nitrogen oxide emission. Plausible reason for this is that advances in feed efficiency, better pasture management, and practices reduce methane emissions per unit of beef produced. Likewise, as beef production increases, the amount of manure produced also increase, leading to higher N_2O emissions. While it is possible for total GHG emissions to be reduced if the decrease in methane emissions is substantial enough, achieving a significant overall reduction in total GHG emissions is challenging if there is a concurrent significant increase in NO_2 emissions. The high global warming potential of N_2O means that managing and mitigating its emission is crucial for achieving meaningful reductions in total GHG emissions from increased beef production.

Poultry meat production significantly reduces CO_2 emission but significantly increase methane and nitrogen oxide emissions, respectively. Specifically, in the long-term, 1% increase in poultry meat production would result in a 0.16% reduction in CO_2 emission but a 0.07% and 0.54 increase in methane and nitrogen oxide emissions, respectively. Increasing poultry meat production can lead to reduced CO_2 emissions due to higher efficiency and less land use, but at the same time it can also result in increased methane and nitrous oxide emissions due to manure management and fertilizer use. However, because poultry produce significantly less methane compared to ruminants and have overall lower GHG emissions per unit of meat produced, the total GHG emissions can still be lower, resulting in a net reduction in the overall GHG emissions associated with meat production.

Furthermore, though pig meat production was found to reduce methane and nitrogen oxide emission by 0.11% and 0.98%, respectively, it is however found to have increasing effect on CO_2 and total GHG emission by about 0.29% and 0.19%, respectively. The reduction in methane and nitrous oxide emissions in pig meat production can be attributed to better feed efficiency, improved manure management, and enhanced production practices. However, the increase in CO_2 and total GHG emissions suggests that the energy-intensive nature of the processes involved, along with the potential increase in feed production and overall scale of production, contribute to higher CO_2 emission, thus outweighing the benefits from reductions in CH_4 and N_2O. For sheep and goat meat production, if there is an increase by 1%, a reduction effect of 0.18 and 1.47 on both CO_2 and nitrogen oxide emissions is deduced whereas it would lead to an increase of about 0.09 for methane emission. The results show that the GHG emission effect of meat production for each of the types of meat is not consistent in the long run. However, it can summarily be noted that 6 out of 16 coefficient values of meat production variables are found to increase greenhouse gas (GHG) emissions. The variation highlights that not all aspects of meat production are equally detrimental or beneficial to the environment.

4.5. Income and Emissions

The result of estimation for this study in column 2 of Table 5 reveals that income is a significant source of greenhouse gas emission (CO_2 model) in South Africa in the long run period. The long-term coefficient of income proxy by GDP is positive (0.159) and statistically significant at a 1% level of significance. This suggest that 1% increase in income increases carbon emissions by about 0.82% if all other factors are considered constant. The result of income is consistent with the *a priori* expectation of this study and likewise previous studies (Yusuf et al., 2020 for West

Table 4: ARDL bounds test for cointegration

Model	Model 1	Model 2	Model 3	Model 4
Lag Order	ARDL (4,1,4,4,4,4,4)	ARDL (4,2,4,4,4,4,4)	ARDL (4,4,4,4,3,4,3)	ARDL (3,4,4,4,4,3,4)
K	6	6	6	6
F-statistic	5.8138	6.6248	9.8648	11.9746
Bounds 10% [I (0), I (1)]	[2.53, 3.59]	[2.53, 3.59]	[2.53, 3.59]	[2.53, 3.59]
Bounds 5% [I (0), I (1)]	[2.87, 4]	[2.87, 4]	[2.87, 4]	[2.87, 4]
Bounds 2.5% [I (0), I (1)]	[3.19, 4.38]	[3.19, 4.38]	[3.19, 4.38]	3[.19, 4.38]
Bounds 1% [I (0), I (1)]	[3.6, 4.9]	[3.6, 4.9]	[3.6, 4.9]	[3.6, 4.9]

Source: Authors (2024)

Table 5: Long-run coefficients based on ARDL Estimation

Column 1	Column 2	Column 3	Column 4	Column 5
Model	Model 1; Total GHG ARDL (4,1,4,4,4,4,4)	Model 2: CO_2 ARDL (4,2,4,4,4,4,4)	Model 3: CH_4 ARDL (4,4,4,4,3,4,3)	Model 4: N_2O ARDL (3,4,4,4,4,3,4)
LnLVS1	−0.006381	−0.070900	−0.111346***	3.173601*
LnLVS2	−0.085358**	−0.162480**	0.065801**	0.542067*
LnLVS3	0.191178*	0.287962*	−0.113172*	−0.976909*
LnLVS4	−0.181119*	−0.175675*	0.089454**	−1.468660*
LNGDPPC	0.178243*	0.159037*	−0.088241*	−0.903374*
LNEC	1.233651*	1.450054*	0.416074*	0.084941

Table 6: Post-estimation diagnostics test result

Test	Model 1: Total GHG	Model 2: CO_2	Model 3: CH_4	Model 4: N_20
	ARDL (4,1,4,4,4,4,4)	ARDL (4,2,4,4,4,4,4)	ARDL (4,4,4,4,3,4,3)	ARDL (3,4,4,4,4,3,4)
Normality test				
Jarque Bera	1.7763	0.5308	2.5064	0.8873
Probability	0.4114	0.7669	0.2856	0.6417
Breusch-Godfrey Serial Correlation LM Test:				
F-statistic	2,6834	0.8454	3.2442	2.3389
Prob. F (2,3)	0.2147	0.5419	0.2356	0.2995
Heteroskedasticity Test: Breusch-Pagan-Godfrey				
F-statistic	2.0173	1.0450	0.4363	1.7300
Prob. F (32,5)	0.2230	0.5560	0.9197	0.3194

Africa; Khan et al., 2020 for Pakistan; Mikayilov et al., 2018 for Azerbaijan; Yuping et al., 2021; Beşer and Beşer, 2017 for Turkey; Ridzuan et al., 2020 for Malaysia; Adebayo and Odugbesan 2020 for South Africa; Anwar et al., 2020 for east Asian countries; Ayobamiji and Kalmaz 2020 for Nigeria; Muhammad et al., 2021 for BRICS, developed countries and developed countries). This finding suggests that economic growth in South Africa has been at the expense of a quality environmental condition, indicating an environmentally unsustainable growth, which might affect the achievement of the SDG goal 12 of sustainable production.

4.6. Electricity Consumption and Emissions

Electricity consumption has a significant positive impact on CO_2 emissions and methane emissions as presented in columns 3 and 4 (Table 5). The relationship with nitrogen oxide emissions is positive but not statistically significant. These findings are consistent with the fact that South Africa's electricity generation relies heavily on coal, leading to increased emissions of CO_2 and other greenhouse gases when electricity consumption rises. This result which is consistent with previous studies (Yuping et al. 2021; Khan et al. 2020; Leitão and Balogh, 2020; Shafiullah et al. 2021; Raihan, 2023), reinforces the need for cleaner energy sources and improved efficiency in electricity use to mitigate greenhouse gas emissions in South Africa.

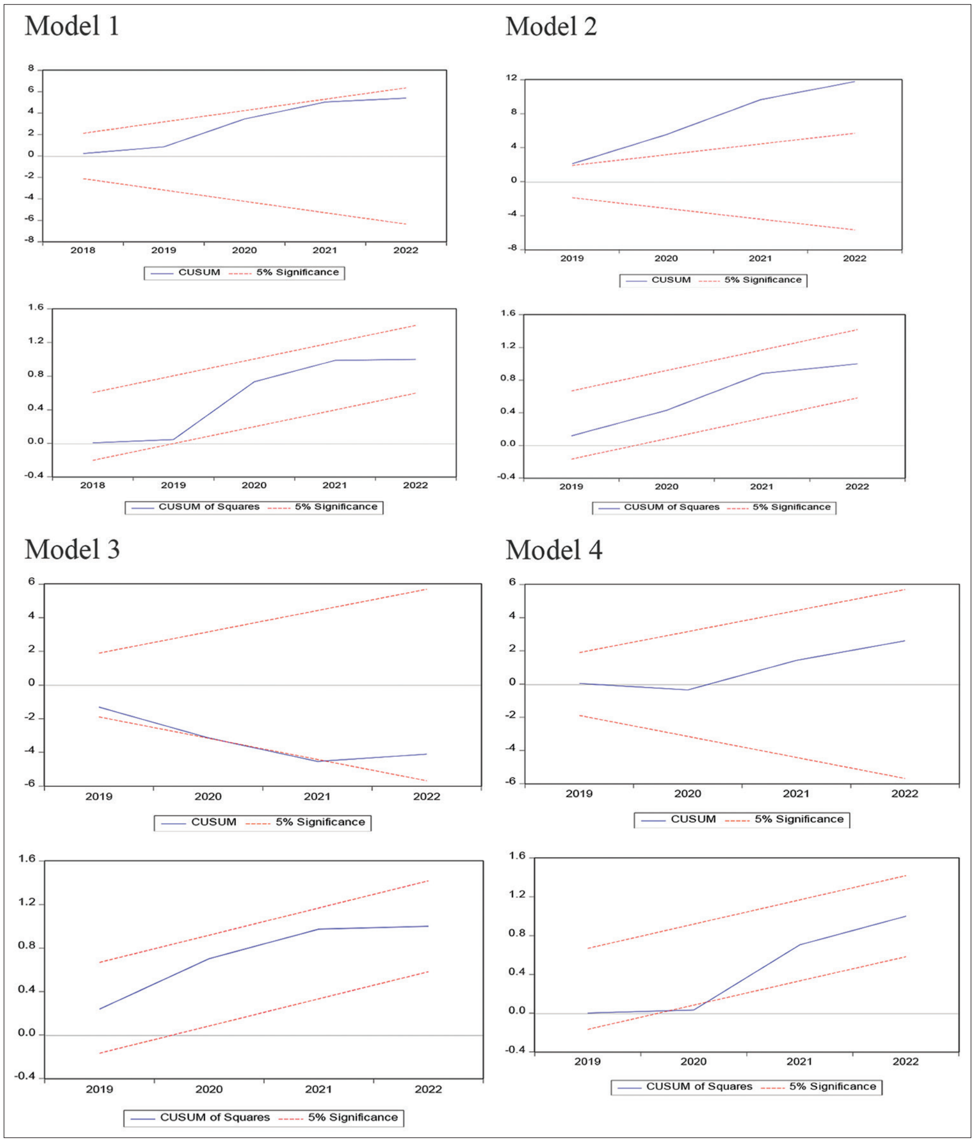
4.7. Post-Estimation Diagnostics

Following the ARDL long-run estimation, three residual diagnostic tests to determine the reliability and stability of each of the models were conducted. The results of each of the models on Breusch–Godfrey Serial Correlation LM tests in the Table 6 suggest that the residuals in the ARDL models are not correlated. The Jarque–Bera values with corresponding P-value showing to be insignificant imply that the residuals of the estimated models are normally distributed as required. Additionally, the stability of the parameters in the longrun period was examined by using the CUSUM and CUSUMSQ tests as proposed by Pesaran and Pesaran (1997). Both the CUSUM and the CUSUMQ plots as shown in Figure 2 are within the 5% significance level, meaning that there is no evidence of long-run parameter instability. Therefore, it can be concluded that the estimated ARDL models are robust and reliable.

5. CONCLUSION, IMPLICATION AND RECOMMENDATION

In view of the dynamics of GHGs emission, it has been put forward those agricultural activities including livestock production is one of the contributors to greenhouse gases emission and environmental pollution. Moreover, the increase in human population, increasing dietary shifts to animal-based

Figure 2: Stability test results



diet and the acknowledged contribution of livestock production to emission warrant a country-level assessment of livestock production and pollution emission relationships. Thus, the effect of meat production alongside control variables (economic growth and energy consumption) on GHG emissions in South Africa was examined in this study. Consequently, ARDL estimation technique was used on times series data for the period 1990-2019 to investigate the nature of relationship and magnitude of effect. Evidence from the results obtained shows mixed results of impact of different livestock production on GHGs emission that in the long-run in South Africa. While beef and buffalo meat production significantly reduce CH_4 emissions it increases N_2O emission. Also, poultry meat production significantly reduces CO_2 emission but significantly increase methane and nitrogen oxide emissions, respectively. Similarly, pig meat production was found to reduce methane and nitrogen oxide emission, it is however found to have increasing effect on CO_2. An increase by 1% of sheep and goat meat production, was demonstrated to lead to a reduction on both CO_2 and N_2O emissions whereas it would lead to an increase in methane emission. Additionally, income is a significant source of greenhouse gas emissions in South Africa. This shows that economic growth in South Africa has been at the expense of a quality environment condition, indicating an environmentally unsustainable growth, which might affect the achievement of the sustainable development goal (SGD) of sustainable consumption and production.

These mixed results underscore the complexity of achieving sustainable livestock production. The increase in N_2O emissions, which has a high global warming potential, suggests that without comprehensive mitigation strategies, efforts to reduce methane emissions through improved production practices might be offset by increases in other potent GHGs. Similarly, the variability in the impact of different types of meat production on GHG emissions indicates that a one-size-fits-all approach to mitigating emissions in the livestock sector may not be effective. For instance, while poultry production might offer a net reduction in total GHG emissions, beef production presents a more complex scenario where reductions in methane could be counteracted by increases in nitrous oxide. Thus, for sustainable livestock production, this implies that sector-specific strategies are necessary. Tailoring mitigation efforts to the specific environmental impacts of each type of livestock production can lead to more effective reductions in GHG emissions, thereby supporting the achievement of SDG goal 12. Furthermore, in the light of this study it is recommended that the South African government provide support for livestock farmers to access, adopt and utilize agricultural technologies that are environmentally friendly and sustainably in their production process.

REFERENCES

Adebayo, T.S., Odugbesan, J.A. (2021), Modeling CO_2 emissions in South Africa: Empirical evidence from ARDL based bounds and wavelet coherence techniques. Environmental Science and Pollution Research, 28(8), 9377-9389.

Ali, B., Ullah, A., Khan, D. (2021), Does the prevailing Indian agricultural ecosystem cause carbon dioxide emissions? A consent towards risk reduction. Environmental Science and Pollution Research, 28(4), 4691-4703.

Ali, E.B., Anufriev, V.P. (2020), The causal relationship between agricultural production, economic growth, and energy consumption in Ghana. R-Economy, 6(4), 231-241.

Ali, S., Liu, Y., Ishaq, M., Shah, T., Ilyas, A., Din, I.U. (2017), Climate change and its impact on the yield of major food crops: Evidence from Pakistan, Foods, 6(6), 39.

Anwar, A., Younis, M., Ullah, I. (2020), Impact of urbanization and economic growth on CO_2 emission: A case of far East Asian countries. International Journal of Environmental Research and Public Health, 17(7), 2531.

Appiah, K., Du, J., Poku, J. (2018), Causal relationship between agricultural production and carbon dioxide emissions in selected emerging economies. Environmental Science and Pollution Research, 25(25), 24764-24777.

Ayobamiji, A.A., Kalmaz, D.B. (2020), Reinvestigating the determinants of environmental degradation in Nigeria. International Journal of Economic Policy in Emerging Economies, 13(1), 52-71.

Ayyildiz, M., Erdal, G. (2021), The relationship between carbon dioxide emission and crop and livestock production indexes: A dynamic common correlated effects approach. Environmental Science and Pollution Research, 28(1), 597-610.

Balogh, J.M. (2020), The role of agriculture in climate change: A global perspective. International Journal of Energy Economics and Policy, 10(2), 401-408.

Balsalobre-Lorente, D., Driha, O.M., Bekun, F.V., Osundina, O.A. (2019), Do agricultural activities induce carbon emissions? The BRICS experience. Environmental Science and Pollution Research, 26(24), 25218-25234.

Balsalobre-Lorente, D., Driha, O.M., Halkos, G., Mishra, S. (2022), Influence of growth and urbanization on CO_2 emissions: The moderating effect of foreign direct investment on energy use in BRICS. Sustainable Development, 30(1), 227-240.

Beşer, M.K., Beşer, B.H. (2017), The relationship between energy consumption, CO_2 emissions and GDP per capita: A revisit of the evidence from Turkey. Alphanumeric Journal, 5(3), 353-368.

Chandio, A.A., Akram, W., Ahmad, F., Ahmad, M. (2020a), Dynamic relationship among agriculture-energy-forestry and carbon dioxide (CO_2) emissions: Empirical evidence from China. Environmental Science and Pollution Research, 27(27), 34078-34089.

Chandio, A.A.A., Jiang, Y., Rehman, A., Rauf, A. (2020b), Short and long-run impacts of climate change on agriculture: An empirical evidence from China. International Journal of Climate Change Strategies and Management, 12, 201-221

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F.N., Leip, A. (2021) Food systems are responsible for a third of global anthropogenic GHG emissions. Nature Food, 2, 198-209.

Dangal, S.R., Tian, H., Zhang, B., Pan, S., Lu, C., Yang, J. (2017), Methane emission from global livestock sector during 1890-2014: Magnitude, trends and spatiotemporal patterns. Global Change Biology, 23(10), 4147-4161.

Demirhan, H. (2020), dLagM: An R package for distributed lag models and ARDL bounds testing. PLoS One, 15(2), e0228812.

Doğan, N. (2019), The impact of agriculture on CO_2 emissions in China. Panoeconomicus, 66(2), 257-271.

Ewetan, O.O., Matthew, O.A., Babajide, A.A., Osabohien, R., Urhie, E. (2020), Fiscal federalism and economic development in Nigeria: An auto-regressive distributed lag approach. Cogent Social Sciences, 6(1), 1789370.

Eyuboglu, K., Uzar, U. (2020), Examining the roles of renewable energy consumption and agriculture on CO_2 emission in lucky-seven countries. Environmental Science and Pollution Research, 27(36), 45031-45040.

Ghosh, S. (2018), Carbon dioxide emissions, energy consumption in agriculture: A causality analysis for India. Arthaniti: Journal of Economic Theory and Practice, 17(2), 183-207.

Grossi, G., Goglio, P., Vitali, A., Williams, A.G. (2019), Livestock and climate change: Impact of livestock on climate and mitigation strategies. Animal Frontiers, 9(1), 69-76.

Haider, A., Rankaduwa, W., Shaheen, F. (2021), Nexus between nitrous oxide emissions and agricultural land use in agrarian economy: An ARDL bounds testing approach. Sustainability, 13(5), 2808.

Hongdou, L., Shiping, L., Hao, L. (2018), Existing agricultural ecosystem in China leads to environmental pollution: An econometric approach. Environmental Science and Pollution Research, 25(24), 24488-24499.

Janjua, P.Z., Samad, G., Khan, N. (2014), Climate change and wheat production in Pakistan: An autoregressive distributed lag approach. NJAS-Wageningen Journal of Life Sciences, 68, 13-19.

Khan, M.K., Khan, M.I., Rehan, M. (2020), The relationship between energy consumption, economic growth and carbon dioxide emissions in Pakistan. Financial Innovation, 6(1), 1-13.

Khan, R. (2020), Agricultural production and CO2 emissions causes in the developing and developed countries: New insights from quantile regression and decomposition analysis. BioRxiv, Available at: https://doi.org/10.1101/2020.11.16.384370

Kumar, P., Sahu, N.C., Kumar, S., Ansari, M.A. (2021), Impact of climate change on cereal production: Evidence from lower-middle-income countries. Environmental Science and Pollution Research, 28, 51597-51611.

Leitão, N.C., Balogh, J.M. (2020), The impact of energy consumption and agricultural production on carbon dioxide emissions in Portugal. AGRIS on-line Papers in Economics and Informatics, 12(1), 49-59.

Lin, B., Omoju, O.E., Nwakeze, N.M., Okonkwo, J.U., Megbowon, E.T. (2016), Is the environmental Kuznets curve hypothesis a sound basis for environmental policy in Africa? Journal of Cleaner Production, 133, 712-724.

Lin, B., Omoju, O.E., Okonkwo, J.U. (2015), Impact of industrialisation on CO_2 emissions in Nigeria. Renewable and Sustainable Energy Reviews, 52, 1228-1239.

Liu, H., Wrage-Mönnig, N., Lennartz, B. (2020), Rewetting strategies to reduce nitrous oxide emissions from European peatlands. Communications Earth and Environment, 1, 17.

Mikayilov, J.I., Galeotti, M., Hasanov, F.J. (2018), The impact of economic growth on CO_2 emissions in Azerbaijan. Journal of Cleaner Production, 197, 1558-1572.

Muhammad, B., Khan, M.K., Khan, M.I., Khan, S. (2021), Impact of foreign direct investment, natural resources, renewable energy consumption, and economic growth on environmental degradation: Evidence from BRICS, developing, developed and global countries. Environmental Science and Pollution Research, 28(17), 21789-21798.

Nabuurs, G.J., Mrabet, R., Abu Hatab, A., Bustamante, M., Clark, H., Havlík, P., House, J.I., Mbow, C., Ninan, K.N., Popp, A., Roe, S., Sohngen, B., Towprayoon, S., Steinfeld, J. (2022), Agriculture, Forestry and Other Land Uses (AFOLU). In: Shukla, P.R., Skea, J., Slade, R., Al Khourdajie, A., van Diemen, R., McCollum, D., Pathak, M., Some, S., Vyas, P., Fradera, R., Belkacemi, M., Hasija, A., Lisboa, G., Luz, S., Malley, J., editors. IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK, New York: Cambridge University Press.

Pesaran, M.H., Shin, Y., Smith, R.J. (2001), Bounds testing approaches to the analysis of level of relationships. Journal of Applied Econometrics, 16(3), 289-326.

Raihan, A. (2023a), An econometric assessment of the relationship between meat consumption and greenhouse gas emissions in the United States. Environmental Processes, 10(2), 32.

Raihan, A. (2023b), The influence of meat consumption on greenhouse gas emissions in Argentina. Resources, Conservation and Recycling Advances, 19, 200183.

Rehman, A., Ma, H., Ahmad, M., Irfan, M., Traore, O., Chandio, A.A. (2021), Towards environmental Sustainability: Devolving the influence of carbon dioxide emission to population growth, climate change, Forestry, livestock and crops production in Pakistan. Ecological Indicators, 125, 107460.

Ridzuan, N.H.A.M., Marwan, N.F., Khalid, N., Ali, M.H., Tseng, M.L. (2020), Effects of agriculture, renewable energy, and economic growth on carbon dioxide emissions: Evidence of the environmental Kuznets curve. Resources, Conservation and Recycling, 160, 104879.

Sarkodie, S.A., Owusu, P.A. (2017), The relationship between carbon dioxide, crop and food production index in Ghana: By estimating the long-run elasticities and variance decomposition. Environmental Engineering Research, 22(2), 193-202.

Sejian, V., Bhatta, R., Malik, P.K., Madiajagan, B., Al-Hosni, Y.A.S., Sullivan, M., Gaughan, J.B. (2016), Livestock as sources of greenhouse gases and its significance to climate change. In: Greenhouse Gases. London: Intechopen. p243-259.

Shafiullah, M., Khalid, U., Shahbaz, M. (2021), Does meat consumption exacerbate greenhouse gas emissions? Evidence from US data. Environmental Science and Pollution Research, 28(9), 11415-11429.

Tarazkar, M.H., Dehbidi, N.K., Ansari, R.A., Pourghasemi, H.R. (2020), Factors affecting methane emissions in OPEC member countries: Does the agricultural production matter? Environment, Development and Sustainability, 23, 6734-6748.

Ullah, A., Khan, D., Khan, I., Zheng, S. (2018), Does agricultural ecosystem cause environmental pollution in Pakistan? Promise and menace. Environmental Science and Pollution Research, 25(14), 13938-13955.

UNDP. (2011), Human Development Report 2011. Sustainability and Equity-A Better Future for All. New York: United Nations. Available from: https://hdr.undp.org/en/content/human-development-report-2011

UNDP. (2019), Human Development Report 2019, Beyond Income, Beyond Averages, Beyond Today: Inequalities in Human Development in the 21st Century. New York: United Nations.

Vetter, S.H., Sapkota, T.B., Hillier, J., Stirling, C.M., Macdiarmid, J.I., Aleksandrowicz, L., Green, R., Joy, E.J., Dangour, A.D., Smith, P. (2017), Greenhouse gas emissions from agricultural food production to supply Indian diets: Implications for climate change mitigation. Agriculture, Ecosystems and Environment, 237, 234-241.

Warsame, A.A., Sheik-Ali, I.A., Ali, A.O., Sarkodie, S.A. (2021), Climate change and crop production nexus in Somalia: An empirical evidence from ARDL technique. Environmental Science and Pollution Research, 28(16), 19838-19850.

World Commission on Environment and Development. (1987), World Commission on Environment and Development: Our Common Future. Vol. 17. Geneva, Switzerland: World Commission on Environment and Development. p1-91.

Yuping, L., Ramzan, M., Xincheng, L., Murshed, M., Awosusi, A.A., Bah, S.I., Adebayo, T.S. (2021), Determinants of carbon emissions in Argentina: The roles of renewable energy consumption and globalization. Energy Reports, 7, 4747-4760.

Yurtkuran, S. (2021), The effect of agriculture, renewable energy production, and globalization on CO_2 emissions in Turkey: A bootstrap ARDL approach. Renewable Energy, 171, 1236-1245.

Yusuf, A.M., Abubakar, A.B., Mamman, S.O. (2020), Relationship between greenhouse gas emission, energy consumption, and economic growth: Evidence from some selected oil-producing African countries. Environmental Science and Pollution Research, 27(13), 15815-15823.