Short and Long-run Impacts of Climatic variables on Agricultural Output in Egypt

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Abstract

The current study employs the autoregressive distributed lag (ARDL) model and bounds testing approach to contigration, proposed by of Pesaran et al., (2001), to estimate the long and short-run impacts of climatic factors on agriculture output in Egypt over the period 1980-2020. Employed climatic variables are per capita CO2 emissions, average temperature, and average rainfall in addition to control variables that include per capita energy consumption (a proxy of mechanisation), fertilizers use (a proxy for technology), rural populations as a percentage of the total population (as a proxy of rural labour force), and domestic credit to the agriculture sector. Phillips–Perron unit root tests confirm that some variables are stationary at level and other variables, including the dependent variable, are individually integrated of order one. According to the ARDL results, there exists a long-run equilibrium relationship between the Egyptian agriculture output and the explanatory variables. In the long run, a 1% increase in CO2 emissions per capita will lead to a %3.72 decrease in agriculture output but an increase of average annual temperature by 1% results in a rise of the Egyptian agricultural value added by 2.962%. Rainfall is found to have a negative but insignificant impact on agrarian output. Regarding the long-run effects of non-climatic factors, a 1% increase in fertilizer use, energy consumption, percentage of rural population to total population, and credit to agricultural sector would result in an increase of the agrarian production by around 1.3%, 4%, 13%, and 0.26%, respectively. With regard to short-run dynamics, the error-correction term has the expected negative sign implying that about 5% of any movements from disequilibrium are corrected for within the same year. It is worth mentioning that the short-run elasticities are found to be lower than their long-run counterparts. The short-run coefficient of fertilizers use has a negative and significant impact of agrarian value added which could be explained by the fact that excessive chemical fertilizer use can alter soil pH, increase pest attacks, acidify soil, decrease organic carbon, and hinder plant growth and yield. Furthermore, the two-period lagged agriculture credit has a negative significant influence on agricultural output. Smallholder farmers face lack of rural finance and difficulty accessing credit due to lack of collateral. Rural labour force is found to significantly and negatively influence agrarian output contradicting prior theoretical expectations. This could be explained in terms of encroachment on agricultural land due to many factors including, inter alia, rapid pace of urbanisation in recent decades and political instability emerged in early 2011. Policy recommendations include, inert alia, enforcing strict regulation of carbon emissions and encroachment on agrarian land, promoting sustainable farming practices, efficient use of water resources through drip and sprinkler irrigation, implementing new credit schemes to rural agricultural centers, and reforming subsidised fertilizer system while raising farmers' awareness regarding the optimal use of fertilizers.

Keywords – Climate change, CO2 emissions, Agricultural output, ARDL bounds testing approach to contigration , **JEL Classification**: Q15 , C32.

المستخلص باللغة العربية

تأثير العوامل المناخية على الناتج الزراعي في مصر في الأجلين القصير والطويل

تستخدم الدراسة الحالية نموذج الانحدار الذاتي بفترات إبطاء موزعة ومنهجية اختبار الحدود للتكامل المتناظر، الذي قدمه Pesaran et al., (2001)، لنمذجة العلاقة – في الأجلين الطويل والقصير– بين الناتج الزراعي (كمتغير تابع) ومجموعة من العوامل المناخية وغير المناخية في مصر خلال الفترة 1980-2020. وتتمثل المتغيرات المناخية المستخدمة في كل من نصيب الفرد من انبعاثات ثاني أكسيد الكربون، والمتوسط السنوي لدرجات الحرارة، والمتوسط السنوي لهطول الأمطار. أما المتغيرات غير المناخية فتشمل استهلاك الفرد من الطاقة (متغير تقريبي لاستخدام الميكنة)، والأسمدة المستخدمة (متغير تقريبي للتقدم التكنولوجي)، ونسبة سكان الريف إلى إجمالي السكان (متغير تقريبي للعمالة الريفية)، والائتمان المحلي لقطاع الزراعة. تؤكد اختبارات Phillips–Perron لجذر الوحدة أن بعض المتغيرات ساكنة عند المستوى وأن البعض الأخر، بما في ذلك المتغير التابع، متكاملة بشكل فردي من الدرجة الأولى، مما يشير إلى صلاحية تطبيق نموذج الانحدار الذاتي بفترات إبطاء موزعة ومنهجية اختبار الحدود لاختبار التكامل المتناظر. وتشير نتائج اختبار الحدود إلى وجود علاقة توازنية طويلة الأجل بين متغيرات الدراسة. في الأجل الطويل، يترتب على زيادة نصيب الفرد من انبعاثات ثاني أكسيد الكربون بنسبة 1% تراجع الناتج الزراعي بنسبة 3.72%، بينما تؤدي زيادة متوسط درجة الحرارة السنوية بنسبة 1% إلى ارتفاع القيمة المضافة في القطاع الزراعي بنسبة 2.962%. أما هطول الأمطار فيؤثر سلبياً على الناتج الزراعي في الأجل الطويل إلا أن ذلك التأثير غير معنوي. وفيما يتعلق بالتأثيرات طويلة الأجل للعوامل غير المناخية، فإن زيادة قدرها 1٪ في استخدام الأسمدة، واستهلاك الطاقة، ونسبة سكان الريف إلى إجمالي السكان، والائتمان المقدم للقطاع الزراعي يترتب عليها زيادة الناتج الزراعي – على الترتيب – بنحو 1.3٪. 4%، 13%، و0.26%. وفيما يتعلق الأجل القصير، فقد جاءت إشارة معامل تصحيح الخطأ سالبة – متفقة مع الإشارة المتوقع نظرياً – وتشير إلى أن حوالي 5٪ من أي انحرافات الأجل القصير عن المسار التوازني طويل الأجل يتم تصحيحها خلال نفس العام. وتجدر الإشارة إلى أن معلمات الأجل القصير أقل من معلمات الأجل الطويل. وقد جاء تأثير استخدام الأسمدة الكيمائية على القيمة المضافة في قطاع الزراعة سالباً ومعنويا، ويمكن تفسير ذلك الامر بأن الاستخدام المفرط لتلك الأسمدة يمكن أن يغير درجة حموضة التربة، ويزيد من هجمات الآفات، ويقلل الكربون العضوي، مما يؤثر سلبا على نمو النباتات والإنتاجية. أضف إلى ذلك، فإن معامل الائتمان الزراعي بفترتي تاخير له تأثير سلبي ومعنوي على الناتج الزراعي، إذ يواجه المزارعون أصحاب الحيازات الصغيرة نقص التمويل الريفي وصعوبة الحصول على الائتمان بسبب نقص الضمانات. وبخصوص أثر القوى العاملة الريفية على الناتج الزراعي في الأجل القصير، فقد جاء تأثيرها سالباً ومعنوياً، الأمر الذي يمكن تفسيره بالتعدي على الأراضي الزراعية بسبب العديد من العوامل منها، تسارع وتيرة التحضر في العقود الأخيرة وعدم الاستقرار السياسي الذي بزغ في بداية عام 2011. وتتمثل أهم توصيات الدراسة في كل من إنفاذ القوانين المتعلقة بانبعاثات الكربون والتعدي على الأراضي الزراعية، وتعزيز الممارسات الزراعية المستدامة، والاستخدام الفعال للموارد المائية من خلال الري بالتنقيط والري بالرش، وتطبيق أنظمة ائتمانية مناسبة للمراكز الزراعية الريفية، وإصلاح نظام دعم الأسمدة مع رفع وعي المزارعين بالاستخدام الأمثل للأسمدة.

الكلمات الاستدلالية:
التغيرات المناخية – انبعاثات ثاني أكسيد الكربون – الناتج الزراعي – تناظر التكامل ونموذج الإنحدار الذاتي بفترات إبطاء موزعة.

تصنيف JEL: C32, Q15 .

1. Introduction:

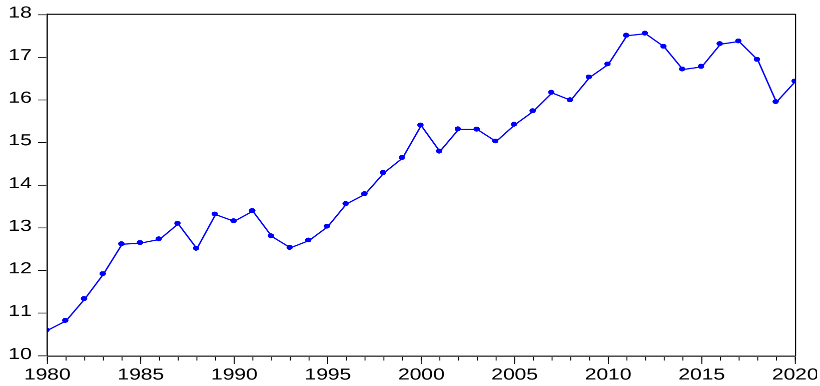
Greenhouse gases, mainly carbon dioxide (CO2), are key drivers of global warming. The intensification of the greenhouse effect has led to climate change (CG) with unprecedented extreme weather events worldwide. Global warming has a disproportionate impact globally regardless of which country contributes more to environmental degradation. Thus, CG is a global concern, with countries committing to the Kyoto Protocol, that came into effect in 2005, and the Paris Agreement adopted in 2015. The latter aims to reduce greenhouse gas emissions. Around 40% of anthropogenic emissions have been trapped in the atmosphere since 1750, with the rest removed by ocean and vegetation sinks. Agriculture, i.e., crops and livestock, is sensitive to CG and its, particularly livestock production, is also a significant source of global anthropogenic greenhouse gas emissions (Sibanda & Ndlela, 2019; Tagwi, 2022; Guan et al., 2023; Otim et al., 2023). The impact of CG on agriculture has been well documented (Deryng et al., 2016; Tagwi, 2022; World Bank, 2021).

According to British Petroleum (2023), the contribution of Africa to global CO2 emissions increased from 2.32 % to 3.8 over the period 1980-2022. Given the high dependence on fossil fuel as the primary energy source in Egypt, it is the second African emitter of CO2 emissions. Figure (1) shows that the CO2 emissions in Egypt, as a percentage of total emissions in Africa, had an upward trend over the aforementioned period, with a significant decline in the most recent period. During 1980-2022, Egypt's contribution to the African and world emissions has risen from 10.6% and 0.2% to around 18% and 0.64%, respectively. Despite the low participation in the world's CO2 emissions, Egypt is one of the countries severely affected by extreme weather patterns given that it ranks as the 83rd most susceptible country facing the threat of climate change and 63rd regarding lack of preparedness to confront climate change (Abou-Ali et al, 2023). Egypt relies heavily on the Nile River for potable water, agriculture, manufacturing, fish farming, power generation, inland river navigation, machinery cooling, and power generation. Egypt is vulnerable to rising temperatures, decreased rainfall in the higher Nile Basins, and lower rainfall along the east Mediterranean coast. Sea level rise is expected to cause significant loss of agricultural land, infrastructure, and urban areas in the northern part of the Egyptian Nile Delta. Key Egyptian sectors affected by CG include water resources, agriculture, fisheries, biodiversity, and coastal zones. The impacts on food production, livelihoods, and food security are significant national concerns. Higher temperatures are expected to negatively impact yields, leading to price increases for important crops (World Bank, 2021).

The Egyptian agriculture sector faces many challenges including water scarcity, changes in rainfall patterns, increasing temperatures, limited cultivation land in the Nile Delta, and land fragmentation and urbanization. Changes in rainfall patterns and temperatures may also affect plant pathogens, and thus, affecting yields (Abdelaal & Thilmany, 2019; Ministry of Planning and Economic Development & UNDP, 2021). Thus, Egypt is expected to be more vulnerable to global food price shocks given that it is food importer. Consequently, increased imports will likely expose the country to severe economic challenges by increasing the food import bill, putting more pressure on the value of the Egyptian pound. Furthermore, this would affect government revenues from the agricultural sector. The economic cost of climate change on Egyptian society would be around US $ 55.3 billion from 2020 to 2050 (Smith et al, 2013; Perez et al., (2021).

Agricultural production is influenced by climatic variables and non-climatic factors. Climatic factors include precipitation, temperatures, and CO2 emissions. Non-climatic factors influencing the agriculture sector include, inter alia, soil fertility, labour, credit to agriculture sector, fertilizers, and energy use and efficiency. Empirical literature shows inconclusive conclusions regarding effect of climatic and non-climatic factors on the agricultural sector e.g., (Faridi & Murtaza, 2013; Abdul Rehman et al., 2017; Koç et al., 2019; Zou, 2020). For example, Ahmad et al (2018) found that short and long-run agricultural output in Pakistan is influenced by formal credit, cropped area, labour force participation, and trade openness. However, labour participation has a positive but insignificant impact. Janjua et al. (2014) and Chandio et al., (2020), for example, conclude that CO2 emissions have a positive long-run impact on the agricultural output. In contrast, Sibanda & Ndlela (2019) found that in the long run, CO2 emissions have an adverse effect on agricultural output, which further has implications on food security for South Africa. Similarly, empirical findings regarding the impact of temperature and precipitation on agriculture value added are inconclusive (see, for example, Dumrul & Kilicarslan, 2017; Ben Zaied and Cheikh, 2015; and Gershon & Mbajekwe , 2020).

Figure (1): CO2 emissions in Egypt to Africa's total CO2 Emission (1980-2020)



Source: British Petroleum (2023).

Elshennawy et al. (2016) used the country-level computable general equilibrium analysis by integrating forward-looking expectations to explore the climatic factors impact and adaptation on long-run growth prospects for Egypt. Compared to a baseline without climate change; they found that the absence of policy-led adaptation investments would reduce real GDP with 6.5% by 2050. They recommended various adaptation measures, including coastal protection investments for vulnerable regions along the low-lying Nile delta, support for crop management practices, and investments to raise irrigation efficiency. They projected that implementing these procedures could reduce the real GDP loss in 2050 to around 2.6%. Tolba et al. (2017) studied the impact of heat changes along Egypt's main climate agricultural zones, i.e. (North Delta, South Delta and Middle Egypt, and Upper Egypt), on the yields of wheat and corn. They found that yield decreased by moving South for both crops; wheat yield reached 2.95, 2.89, and 2.23 ton/feddan in the three zones, respectively, while it reached 3.369, 3.047, and 2.389 ton/feddan, respectively, for corn.

Those yield variations were statistically significant, and the Egyptian economy loses about LE 1485 million yearly due to climate variation among climate zone.

Nassr et al. (2021) analyse the potential economic and social impacts induced by the deterioration of weather conditions on economic growth and food security in Egypt using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), which is a system of network of linked models. The main components include climate models, crop models, and water models. They found that climate change will reduce aggregate food production between -3% (in 2030) and -3.8% (in 2050). Furthermore, it will lead to a rise in the general level of prices, resulting in a decrease in per capita food consumption by around -1.7% and -3.8% during 2030 and 2050, respectively, leading to an increase in hunger. Another branch of studies examined the factors affecting the production and productivity of the Egyptian agriculture sector. Soliman (2017) applied the vector autoregressive (VAR) model and Granger causality test to explore the relationship between public investment and the growth of the agricultural sector. Their results show the existence of one-directional causality between investment and growth, and public investment strongly and positively affects the growth of the agricultural sector. Regarding the impact of credit on the agriculture sector, Rihan and Bawady (2023) evaluated the role of agricultural policies in the Egyptian agricultural sector. They found that the value of agricultural investments, medium-term loans for Egyptian plant production, subsidies, and gross domestic product are crucial determinants in enhancing the agriculture sector.

Based on the above discussion and according to the best of the authors' knowledge, the current paper is the first attempt to employ autoregressive distributed lag (ARDL) bounds testing approach to cointegration, proposed by of Pesaran et al., (2001), to investigate the short- and long-term impacts of climatic variables (i.e., rainfall, temperature, and CO2 emissions) on the **agriculture output** in Egypt over the period extending from 1980 to 2020. Furthermore, it investigates short- and long-run effects of a set of non-climatic factors on the agricultural value added in Egypt over the aforementioned period. Following empirical research (e.g., Faridi & Murtaza, 2013; Zou, 2022; Ahmad et al., 2018), this set of control variables includes energy consumption as a proxy of mechanisation, rural population as a proxy for the rural labour force, and domestic credit to the agricultural sector. The paper hypnotizes that there exist a long and short-run relationships between the Egyptian agriculture output and the explanatory variables. Appropriate mechanisation can maximise revenue, cut expenses, and boost production. It saves operating hours, preserves natural resources, and improves farm operations. Mechanisation is required due to the dearth of labour in the agricultural sector, which accounts for 21% of all employment in Egypt. Farm mechanisation has the potential to turn small farms into sustainable businesses, boosting output and raising the standard of living for low-income farming households (Sayed et al., 2023). Financial constraints negatively influence agricultural value added, lowering farmer income. Timely availability of inputs like seeds, fertilizer, pesticides, and machines can significantly increase agricultural output. Thus, access to timely and adequate rural credit is essential boosting agricultural production (Ahmed et al., 2018; Chandio et al., 2022)

In line with the existing literature (e.g., Chandio et al., 2020; Chandio et al., 2022), a natural logarithmic transformation is applied to all variables, indicating that estimated coefficients are interpreted as elasticities of agricultural output in response to changes in the employed independent variables. Results of the ARDL model show a long-run equilibrium relationship between Egyptian agriculture output and explanatory variables. In the long run, a 1% rise in CO_2 emissions per capita decreases agriculture output by 3%, while an increase in average annual temperature increases agricultural value added by 2.962%. Rainfall has a negative but insignificant impact, but a 1% increase in fertilizer use, energy consumption, and credit to the agricultural sector increases agrarian production by 1.3%, 4%, 13%, and 0.26%, respectively, in the long run. Short-run elasticities are lower than their long-run counterparts, with fertilizer use negatively impacting agrarian value added. Policy recommendations include adopting strict regulation of carbon emissions, promoting sustainable farming practices, efficient water resource use, implementing new credit schemes to rural agricultural centers, and reforming subsidised fertilizer systems.

The rest of the paper is structured as follows: Section 2 provides review of relevant literature whereas section 3 presents an overview of the agricultural sector in Egypt. Data and methodology are introduced in section 4 while section 5 is devoted to discuss empirical findings. Finally, section 6 concludes highlighting policy implication, limitations of the study, area for further research.

2. Literature Review:

Agricultural production is influenced by climatic variables (e.g., precipitation, temperatures, CO_2 emissions) and non-climatic factors (e.g., fertilizers, and energy use). The empirical literature shows inconclusive conclusions regarding effects of climatic and non-climatic factors on the agricultural sector. Regarding climatic variables, higher atmospheric carbon dioxide concentrations significantly enhance crop yields by increasing photosynthesis rate, promoting growth, and decreasing water loss through transpiration. Global climate impact assessments for crops have primarily focused on the impacts of elevated atmospheric carbon dioxide on yields with limited analysis that considers the dual effect on yield and water use in different regions. To study these effects, Deryng et al. (2016) simulated changes in crop yield and evapotranspiration for wheat, maize, soybean, and rice crops. They aimed to estimate crop water productivity by examining the amount of yield produced per unit of water. Their results were derived from 30 simulations of six global crop models under a scenario where carbon dioxide concentrations double by 2080. They found that crops grown at 2000 levels of carbon dioxide would experience severe declines due to higher temperatures and drier conditions. However, when grown at doubled levels, all four crops perform better due to increased photosynthesis and crop water productivity, partially offsetting the impacts of climate change. Maize experiences yield losses due to doubled carbon dioxide levels, while rainfed wheat experiences a 10% increase in yield and 8% increase in yield in arid climates. These rainfed crops, which make up only a small percentage of total wheat worldwide, are often grown in developing countries, making yield fluctuations crucial for food security. Chandio et al., (2020) conclude that CO_2 emissions have a positive long-run impact on the Chinese agricultural output at 5% significance level. A 1% increase in CO_2 emissions can increase the agricultural output by 0.0613%. Their results are consistent with those of Janjua et al. (2014).

Similarly, Otim et al (2023) found that in the long run, labour, renewable energy consumption, CO_2 emissions, and arable land have a positive effect on crop production in East African Community (EAC) countries. This could be explained by the fact that higher concentration of CO_2 emissions increase photosynthesis process and suppresses transpiration of some crops (e.g., wheat).

However, their results show that governance negatively influences crop production while gross capital formation has no significant effect on crop production. Otim et al (2023) concluded that livestock production in the EAC countries is positively affected by labour, CO_2 emissions, renewable energy consumption, governance, and arable land. On the other hand, Sibanda & Ndlela (2019) found that in the long run, CO_2 emissions have an adverse effect on agricultural output, which further have implications on food security for South Africa.

Results of Edoja et al. (2016) revealed that there is a negative and significant short run association between CO_2 emissions and agricultural productivity and between carbon emissions and food security in Nigeria. Granger causality test showed that there was a unidirectional causality running from CO_2 emissions to agricultural productivity and also from these emissions to food security. Moreover, the variance decomposition analysis confirmed that CO_2 emissions contributed about 23% and 22% to the variation in agricultural productivity and food security, respectively. Agba et al. (2017) found that rainfall has a positive and significant impact on crop output in the short and long run whereas temperature and CO_2 emissions have a negative and significant effect on crop production only in the long run in Nigeria. The consumption of toxic CO_2 emissions by vegetation can negatively impact plant quality, aesthetics, and economic value. When CO_2 sinks in the atmosphere, it can harm vegetation and aquatic life, causing harm to both plants and aquatic life. Gershon & Mbajekwe (2020), investigating the association between climate change (measured by mean annual rainfall, temperature and carbon dioxide emissions) and agricultural production (crop and livestock) in Nigeria over the period 1981-2017, found evidence that rainfall and CO_2 emissions have a positive and significant effect on crop yield but temperature has a negative and significant effect on crop yield in the long run. Moreover, they concluded that four period lagged rainfall has a positive and significant effect on livestock production; two-period lagged temperature has a negative significant influence and one-period lagged CO_2 emissions has a negative significant effect on livestock production in Nigeria.

Results of Dumrul & Kilicarslan (2017) revealed that the temperature has a positive and significant long-run impact on the Turkish agricultural output, however, the rainfall has a negative and significant long-run effect on it. A recent study by Mubenga-Tshitaka et al., (2023) revealed that temperature variability has a long-run impact on agricultural output whereas precipitation variability has a short-run effect on agricultural output in East African countries. Their findings also revealed that the long-run temperature variability effect is heterogeneous across East African countries, and to some extent, there is also evidence for the long-run effect of precipitation variability.

Blanc (2012) examined the influence of CG on yields for the most commonly grown crops (millet, maize, sorghum and cassava) in Sub-Saharan Africa by employing panel data approach for the period 1961-2002 for 37 countries. He found that the impact of precipitation on crop yields depends on national agricultural conditions. Additionally, CG is predicted to decrease yields for all crops except cassava. Ben Zaied and Cheikh (2015) applied the panel cointegration tests to estimate the long-run effects of CG on crops in Tunisia. They found that higher annual temperature reduces cereal and date outputs, except in highland areas. Furthermore, the rainfall positively impacts cereals, however, rain shortages in the South affect output negatively in this region. Moreover, they reported that the short-run climate effects are smaller than the long-run effects. Ray et al. (2019) evaluated the potential impact of CG on the yields of the top ten global crops (namely barley, cassava, maize, oil palm, rapeseed, rice, sorghum, soybean, sugarcane and wheat). They found that global CG harms crop yields. Moreover, the results indicated that the climatic impact is highly dependent on the region. In other words, effects are primarily negative in Europe, Southern Africa and Australia but in general positive in Latin America whereas impacts in Asia and Northern and Central America are mixed.

Non-climatic factors influencing the agriculture sector include, inter alia, soil fertility, labour, credit to agriculture sector, fertilizers, and energy use and efficiency [e.g., Faridi & Murtaza, 2013; Rehman et al., 2017; Koç et al., 2019; Zou, 2020; Ayumah et al., 2020; Chandio et al., 2022]. Neo-classical and endogenous growth theories argue that core factors of growth include labour, capital, human capital, and technological progress (Solow, 1956, 1957; Romer, 1990). Energy plays a crucial role in economic growth, as it drives economic activity and enhances production. Energy is needed for technological advancement and the usage of mechanisation in production. Quality energy resources can facilitate new technology, while less valuable ones can dampen its power (Faridi & Murtaza, 2013). Wei (2007) incorporated energy efficiency use into Cobb-Douglas function and theorized about short-term and long-term effects energy efficiency. Beginning with the production function specification as function of labour, capital and some measures of energy consumption, Wei (2007) concluded that energy use efficiency is found to lower the cost of non-energy goods and increase output of non-energy goods. However, a 100% rebound effect is observed, meaning that short-term efficiency gains do not affect absolute energy use. In the long term, energy end-use efficiency positively impacts non-energy output. Energy consumption in agriculture has increased as a result of the growing usage of mechanical equipment (Zafeiriou et al., 2023).

Results of Faridi & Murtaza (2013) revealed that total energy and total gas consumption have a significant and positive influence on GDP and agricultural output, however, electricity consumption is found to significantly and negatively affect both GDP and agricultural output in Pakistan. The negative impact of electricity use is explained by the fact that continuous shortfall of the electricity and electricity supply shocks are the main causes of growth deterioration in Pakistan. Moreover, they found that the agricultural credit contributes positively in boosting up agricultural output. Credit to agriculture sector directly affects agricultural productivity through investment and financing of seeds and fertilisers. Sial et al (2011) concluded that agricultural credit has a positive and significant impact on agricultural output in Pakistan over the period 1972-2008 whereas water availability, crop intensity, agricultural labour force per cultivated hectare are the factors that enhance agricultural output. Similarly, Ahmad et al (2018) confirmed that agricultural output in Pakistan as a dependent variable shares a long-run equilibrium relationship with agricultural formal credit, cropped area, labour force participating in the agriculture sector, and trade openness over the period 1973-2014. Agriculture credit and cropped area have significant and positive impacts on agriculture output whereas labour participating in agriculture has a positive but insignificant impact on it. The availability of agricultural inputs like seeds, fertilizers, pesticides, mechanization of tractor and tube wells, and other farm-related activities requires sufficient formal credit provision. Ahmad et al (2018) concluded that trade openness has a significant and negative influence on agricultural output in Pakistan.

Employing time series data over the period extending from 1953 to 2020, Zou (2022) concluded that energy consumption is a driving force for the growth of agricultural production in China. Applying the two-way fixed-effect model and panel vector autoregressive (PVAR) model onto data of 30 provinces and municipalities in China from 2005 to 2019, Guan et al (2023) analysed the static and dynamic relationship between agricultural mechanization, large-scale operation and agricultural carbon emissions. Agricultural mechanization is the use of advanced machinery to enhance agricultural production and operation conditions, thereby enhancing economic and ecological benefits. Large-scale operations primarily benefit from rural labour outflows from agricultural production, but excessive chemical energy input, such as fertilizer and agricultural film, may be generated to maintain output levels, thereby increasing agricultural carbon emissions. Findings of Guan et al (2023) revealed that agricultural mechanization and large-scale operations increase agricultural carbon emissions. However, there is a two-way causality relationship between mechanization and carbon emissions. Mechanization is a sustainable cause of CO_2 emissions, while large-scale operations have a positive short-term effect and ultimately help reduce these emissions in the long run. Thus, they suggested that the government should accelerate research and development of clean energy-powered agricultural machinery and encourage farmers to reduce chemical input, improve pesticide use efficiency.

Chandio et al. (2018) examined the short and long-run determinants of grain crop productivity in Pakistan by employing the ARDL approach to cointegration from 1978 to 2016. They provided evidence that grain crop area, fertilizer, improved seed, and water availability positively affect productivity. Chandio et al. (2019) confirmed the positive and significant effect of land area and fertilizer on wheat production in Pakistan over the short and long runs. Ketema (2020) applied the ARDL model and the bounds testing approach to cointegration to investigate Ethiopia's long-run and short-run determinants of agricultural output. They found that rainfall, fertilizer inputs, trade openness, and inflation rate affect the output positively and significantly, while drought negatively affect agricultural output in the long run. In the short run, fertilizer input import and labour force show positive and significant effects, whereas drought has a significant but negative impact on agricultural output.

Applying the ARDL model and the bounds testing approach to cointegration onto annual dataset from 1988–2014 in Bangladesh, Chandio et al., (2022) found stable long-run relationship between cereal production as a dependent variable and a set of climatic and non-climatic factors. Climatic factors include temperature, rainfall and CO_2 emissions whereas employed non-climatic factors include cereal cropped area, financial development proxied by domestic credit to the private sector, energy consumption, and labour force. In the long run, temperature and rainfall positively influence cereal production but CO_2 emissions have significant and negative impacts. Non-climatic factors have positive long-run impacts on cereal production. In the short run, temperature and CO_2 emissions have negative impacts on cereal production, while rainfall and non-climatic factors have positive and significant positive impacts on it. Rehman et al., (2017) reached mixed conclusions regarding the impact of agricultural credit on agricultural output in Pakistan over the period 1960-2015. They concluded that the total food production, loan provided by Zarai Taraqiati Bank Limited[1] and total loan disbursed by various institutions has a positive and significant influence on the agricultural output, whereas cropped area and loan disbursed by cooperatives has a negative but insignificant influence on the agricultural output. Financial constraints in developing economies contribute to backwardness, negatively impacting agricultural output and farmer income. Eliminating these capital imperfections can improve agricultural productivity. In order to assess the effect of domestic policy measure and subsidized credits use on agricultural output (measured as agricultural value added) in Turkey, Koç et al., (2019) applied a spatial production function including land, labor, chemical inputs, capital (number of tractors used as proxy of capital), agricultural policy supports payment, and agricultural credits use per hectare onto a provincial-level panel data in 2004–2014. Their empirical findings revealed that agricultural growth in a given province does not only rely upon its production factor endowment, but also the agricultural supports received, agricultural credits used and agricultural growth in its neighbouring provinces. Moreover, main inputs improving provincial agricultural growth include chemical fertilizer, pesticide and agricultural credits whereas agricultural supports measure has significant and negative impact on agricultural growth due to the spillover effect.

3. The Agriculture Sector in Egypt: An Overview

In early 1950s and during the 1960s, agriculture was pivotal to Egypt's development policies, with rural residents and manufacturing workers at the center of national Egyptian identity. During this period, government intervention was driven by political objectives, aiming to acquire foreign exchange through agricultural exports, provide low-priced food to the growing population, and achieve wealth and income distribution equity. The agriculture sector has been affected by many government interventions, including sector-specific policies and direct intervention measures. The Egyptian government in the 1950s implemented key policies to regulate the agricultural sector, including agrarian land reform, which limited land ownership and regulated the relationship between owners and tenants. This aimed to redistribute wealth and transform Egypt's skewed land tenure system. The law also set a maximum limit on land ownership at 50 feddans per family and a limit on cash rent. The direct intervention measures include crop rotations system with the aim of regulating crop production and ensuring scientific crop planning for improved yield and pest control. Moreover, pricing regulations were imposed on agricultural commodities to ensure affordable food for the population. To achieve this, the government established cooperatives, which regulated crop rotations, provided subsidized inputs and credit facilities, and purchased agricultural production at pre-determined prices. However, these regulations resulted in a heavily taxed agricultural sector, negatively impacting agricultural development and food security. In addition, economy-wide or macroeconomic and trade policies pursued by the government have indirectly affected agricultural performance. The overvalued exchange rate led to capital artificially being cheaper, increasing the bias towards capital-intensive projects. This led to a worsening of the economy-wide incremental capital-output ratio from 2.5 in 1976-81 to 6.5 in 1984-88, indicating inefficiency of investment. The system of tight import controls, low domestic energy prices, and low interest rates resulted in suboptimal investment allocations, stressing capital- and energy-intensive projects while neglecting labor-intensive investments in agriculture and domestic raw material processing. Agriculture stagnated as a result of these interventionist institutional structures, frustrating farmers, declining yields, altered planting patterns, declining exports, and widening disparities in crop self-sufficiency (Gouell and El Miniawy, 1994; Ikram, 2006; Kassim et al, 2018; Elwi, 2019; el Sayed, 2021).

In 1986, the Egyptian government initiated a series of economic reforms to eliminate distortions in the economy and to promote sustainable growth in the productive sectors. Several measures have been implemented to reduce restrictions in the agricultural sector. Between 1987 and 2002, two agricultural policy reform programmes were implemented. They are the Agricultural Production and Credit Project (1987-1995) and the Agricultural Policy Reform Programme (1996-2002). The first project reduced subsidies in agricultural inputs, removed controls on area allotments, and removed price and marketing restrictions for major crops. The Agricultural Policy Reform Program followed, which included the privatization of public firms. The Economic Reform and Structural Adjustment Program, launched in 1991, accelerated market liberalization and encouraged private sector involvement in agriculture trading by removing most subsidies, lifting mandatory crop rotations, and removing pricing and marketing controls (Gouell & El Miniawy, 1994; Kassim et al, 2018; Elwi, 2019).

The government's current strategy aims to develop efficient agriculture and export opportunities, bringing poor smallholder farmers into the mainstream of economic activity, enhancing food security, incomes, and creating employment opportunities. The Agricultural Sustainable Development Strategy 2030, prepared in collaboration with the International Fund for Agriculture and Development (IFAD)[1], focuses on sustainable use of natural resources, increasing productivity, food security, competitiveness of agriculture products, improving investment climate, and job creation, particularly for rural youth. The strategy also emphasizes strengthening producer associations, making market information more accessible, enacting and enforcing product standards laws, linking agricultural extension to research, and developing the private sector's extension role (IFAD, 2012).

Investment and financing strategies are crucial for the growth and support of the agriculture sector. The Egyptian Agriculture Bank, previously known as the Principal Bank for Development and Agricultural Credit (PBDAC)[1], provided universal credit subsidies to both large agriculture corporations and smallholder farmers, accounting for 70% of formal institutional lending to the agriculture sector in 2014. However, the sector's access to credit remains inadequate, receiving only 1% of total lending compared to 38% and 26% for the industry and services sectors, respectively. Lack of access to finance prevents timely purchases of inputs, especially expensive ones, which results in "tied" transactions and weaker bargaining power, impeding the growth of Egypt's agricultural and rural sectors. In addition, Financial constraints exist along the value chains of some agricultural commodities, leading to post-harvest losses for farmers and restricted uptake. Small and medium-sized businesses (SMEs) and agricultural and rural sectors cannot receive services from the commercial banking sector because it lacks the necessary knowledge, expertise, and risk appetite (IFAD, 2012; Kassim et al, 2018).

Regarding the distribution of loans provided the Egyptian banking system by economic activity over the period 1991-2014, the manufacturing sector was a major recipient of loans in both local and foreign currencies with around 37.9% of total loans in 2014 whereas services and trade accounted for about 23.7% and 10.2%, respectively in the same year. Credit directed to agriculture over the aforementioned period is quite small because it did not exceed 2% of total loans (Ahmed, 2017). According to (CBE, 2022), credit received by the agriculture sector represented around 1.5% of total lending by the Egyptian banking sector by the end of December 2021, while unclassified sectors (including household sector), manufacturing, services, and trade received 35.8%, 30.6%25.1%, and 7%, respectively. In recent years, nearly all banks shifted their interest towards the retail business (or individual service) including credit cards, personal loans, ATM cards, retirement and salary payments. Such shift in their interest could be explained by the fact that retail services are associated with lower risk lending when compared with corporate lending.

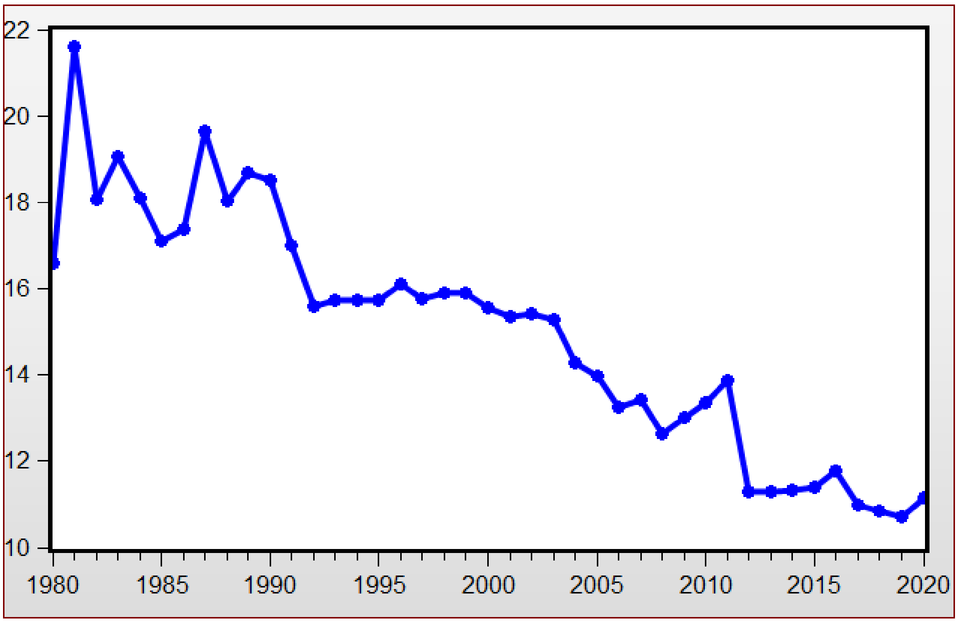
With an emphasis on creating supportive programmes, increasing agricultural land, and advancing the mechanisation of the agricultural tenure system, the 2018–2022 Sustainable Development Medium-Term Plan allocates direct investments of LE 217 billion to the agricultural sector. A database of holders and audited data will also be created as part of the strategy to track waterway development, agricultural development projects, and water use rationalisation. Increasing net foreign direct investment (FDI) to $11 billion in 2018–2019 and $20 billion in 2021–2022 is the goal of this strategy. However, compared to other economic sectors, agriculture’s share of investment is still small, with the majority allocated to services, trade, and industry. In order to assist exporters and lessen their financial strain on tax and administrative systems, agricultural policies have been changed. The investment climate has significantly improved as a consequence, with agricultural industries—especially land reclamation—leading the way in terms of tax-free activities. Priority is also given to agricultural exports when it comes to funding and outside marketing costs. Reducing conflicts between laws and regulations controlling direct and indirect agricultural investments is the long-term objective. Another is coordinating amongst departments and agencies that are responsible in relation to agricultural investment, its services, and its requirements (Sultan, 2020).

Agriculture represents a significant sector of the Egyptian economy. In 2020/2021, the industry sector was the highest contributor to GDP with around17.5%, followed by retail (14.8%), and agriculture (12.4%) (FAO, 2023). Figure (2) displays the agriculture contribution to GDP during the period 1980-2020. According to Figure 2, this contribution jumped from 16.6% in 1980 to 21.6% in 1981. This is followed by fluctuations around a declining trend to reach 11.2% in 2020. The surge in its contribution to GDP in 1987 may be attributed to the measures undertaken by the Egyptian government in 1986, as mentioned before. The contribution of agriculture to GDP dropped in 2004 which could be explained by the devaluation of the Egyptian pound against the US dollar in January 2003 and the increase in energy prices that raised production costs. Moreover, the decline in the agricultural sector's contribution to GDP in 2008 could be explained by internal and external shocks, including the avian flu that led to a decline in livestock production and the global financial crisis in 2007 that negatively influenced different economic activities. Despite the political instability in 2011, the share of agriculture to GDP increased due to the increase in agricultural output to cover the increasing demand for food products. However, the continuous political unrest led to a drop of 24.4% in the growth rate of agricultural production between 2012 and 2013, resulting in a drop of agriculture contribution to GDP. Further, there was a contraction in the agriculture output in (2017-2019) as a result of the floating of the Egyptian Pound in November 2016; however, this was followed by a recovery in 2020 (Ahmed, 2012; Gebril, 2021). Generally, the declining trend of the agriculture share to GDP over the sample under consideration is due to the small percentage of fixed investment allocated to agriculture over this period (Gouell & El Miniawy, 1994; Soliman, 2017).

Egypt's farm production is a mix of crop cultivation and livestock production, with growers cultivating crops across three seasons: winter (October-April), summer (May-September), and a third season called nili (August-late fall). Winter crops include wheat, clover, sugar beets, and vegetables, while summer crops include rice, maize, cotton, and sorghum. In the nili season, maize, rice, and potatoes are the most popular crops, while sugar cane and fruit crops are popular permanent/perennial crops. Small landholders raise livestock like cows and water buffalo on diversified farms for extra income and home consumption (Abdelaal & Thilmany (2019).

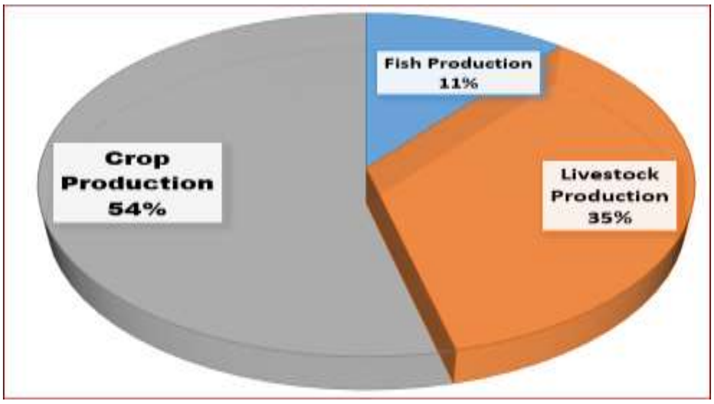
Figure (3) shows the relative importance of different subsectors in the Egyptian agricultural sector. According to Figure 3, plant production dominates Egypt's agricultural sector, contributing 321.8 LE billion, about 54% of the agricultural output during 2019/2020. Field crops, such as cotton, wheat, rice, and maize, represent more than 61% of the plant production subsector, followed by vegetables accounting for 19.86.5%, and fruits crops, fruit seedlings, and wood trees at 16.7%. Furthermore, the share of livestock represents 35% of total agriculture value added, whereas fish production accounts for 11% of total agricultural output. Regarding the sector's ability to create jobs, Figure (4) displays the employment in the agriculture sector to the total labour force over the period (1990- 2020). The pattern of agriculture contribution to the total labour force is very similar to the share of agricultural production to GDP shown in Figure (2). The participation of the agriculture sector in employment has declined from 37.7% to 19.8% during the period. This could be attributed to the decline in investments devoted to this sector (Soliman, 2017).

Figure (2): The share of agricultural output to GDP (1980-2020)



Source: World Bank, World Development Indicators.

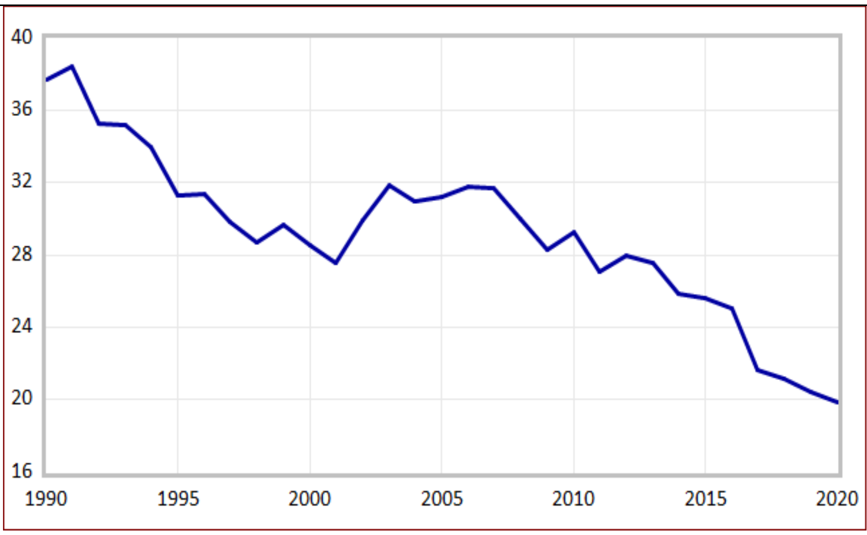
Figure (3): Composition of agriculture output in 2019/2020



* Insecticide Production represents only 0.04% of agricultural production

Source: CAMPAS (2020).

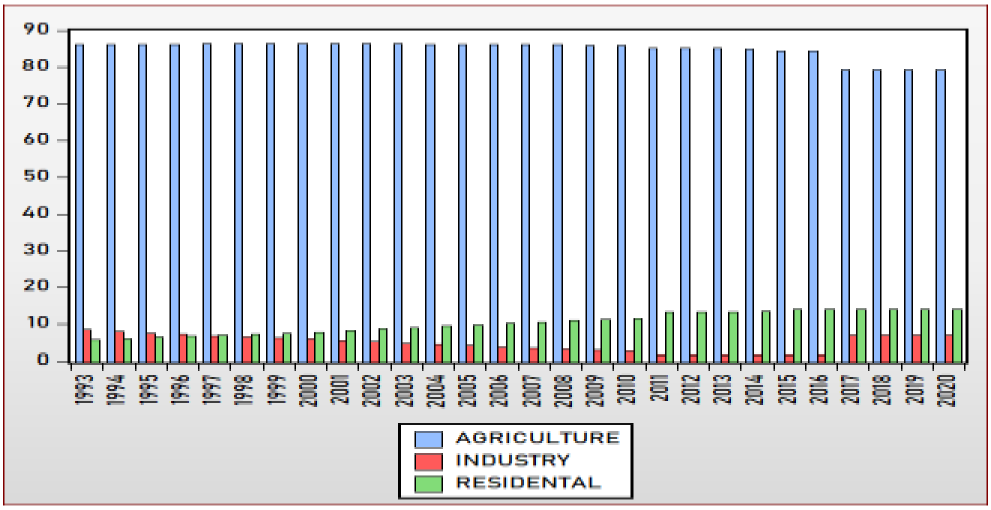
Figure (4): Employment in the agricultural sector to total labour force (1990-2020)



Source: World Bank, World Development Indicators.

By the mid-1990s, the Egyptian government initiated several national projects to expand horizontal agriculture. Toshka project[1] is considered one of the most important projects, aimed at adding 540 thousand feddan, with 92% of these projects being implemented in 2007. Thus, 2006 and 2007 witnessed the maximum addition to the agricultural area's capacity (Gebril, 2021). Other projects include Alsalam Canal Project, aimed at reclaiming 620,000 feddan, and the East Owainat Project to reclaim 220,000 feddan. On the other hand, the total area of agricultural land that was encroached on during the period 1983-2010 before the January Revolution was about 64,012 feddan, while the encroachments during the period 2011-2020 (i.e., the period after the revolution) amounted to about 82,004.5 Feddan. According to (Abdelaal, 2022), the annual average of encroachments on agricultural land in the first period reached 2286.18 feddan, compared to 9111.96 for the second period despite the issuance of legislation and laws to limit encroachments on agricultural land. Moreover, most of the encroachment occurs in the governorates in the Nile Delta compared to governorates in Upper Egypt, which is attributed to the number and density of the population in the first governorates compared to the governorates of Upper Egypt. Factors contributing to the loss of agricultural land include decay of the executive authorities, fast growth of population, and the low value of agricultural land. The Egyptian government has adopted several laws to prevent urban encroachment on agricultural land, including Agriculture Law No. 53 in 1966, Law No. 116 in 1983, Law No. 4 in 1994, and Law No. 119 in 2008. Nevertheless, these laws were insufficient in protecting agricultural land due to the inability of authorities to enforce them, especially after the 2011 revolution. Overpopulation has increased demand for land for housing and human activities, leading urban poor to illegally build houses on agricultural lands especially when the land is already equipped with basic infrastructure, primarily water and electricity. Moreover, urban encroachment on agricultural land is accelerated by decreasing land value that encourages farmers to convert their lands to urban uses, given the low returns from agriculture (Salem, 2020).

Figure (5): Freshwater withdraws (percentages of total water withdraws) by sectors over the period 1993-2020



Source: World Bank, World Development Indicators.

Due to the effects of climate change, there is a great deal of uncertainty regarding the quantity and timing of Nile River water that Egypt can access. Nearly all of Egypt's freshwater resources (around 97%) come from the Nile River. The availability of water in Egypt will be greatly impacted by changes in the Nile Basin's temperature, evapotranspiration, and precipitation brought on by climate change (World Bank, 2022). The 1959 agreement between Egypt and Sudan determined Egypt's share of the Nile's water to be 55.5 billion cubic meters annually (Gouell and El Miniawy, 1994). Recently, Egypt's agricultural sector has faced a massive challenge, given that building the Grand Ethiopian Renaissance Dam (GERD) on the Nile River raises severe concerns about water availability in Egypt. As mentioned earlier, no significant procedures have been reached to accommodate the economic and environmental impacts resulting from the operation of GERD despite the agreement signed by Ethiopia, Egypt, and Sudan to conduct studies on the potential influence of GERD on the Nile River in 2015 (Ahmed & Ahmed, 2019).

Figure (5) presents water withdrawal, which evaluates the rivalry and reliance on water assets. As shown in the figure, agriculture represents the highest water withdrawal compared to other sectors. According to the displayed data, agriculture withdraws of water declined from 86% to 79% during the period 1993-2020, which is still high compared with the world average of 70% in 2020 (World Bank, 2023). Additionally, industry reliance on water resources declined from 8% to 7%, whereas the residential usage of water resources increased from 6% to 14% over the same period. Concerning rainfall, it is almost entirely limited to the northern coastal region and a few kilometres inland, where the average annual precipitation ranges from 65-190 mm. The Nile Delta and adjacent areas receive 25-65 mm of rainfall annually. Areas south of Cairo, in Middle and Upper Egypt, average about 25 mm annual rainfall. With minimal cloud cover, sunshine falls on the ground surface well over 90% of the time (Gouell and El Miniawy, 1994).

4. Data and Methodology:

In order to investigate the short and long-run effects of climatic factors and non-climatic variables on the Egyptian agriculture output, the current paper applies the ARDL bounds testing approach to contigration, introduced by Pesaran et al., (2001), onto annual data covering the period extending from 1980 to 2020, with 41 observations. Table no. 1 displays data description, measurement, and sources. Following empirical literature (e.g., Janjua et al., 2014; Chandio et al, 2018; Chandio et al., 2020), employed climatic determinants are per capita Carbon dioxide emissions, average annual temperature, and average annual rainfall. With regard to non-climatic factors, empirical literature (e.g., Sial et al., 2011; Rehman et al., 2017; Chandio et al., 2020; Chandio et al., 2022) identifies a number of variables including fertilizer consumption (a proxy for technology advance), energy consumption (a proxy for mechanisation), credit to agriculture, and rural population as a percent of total population (a proxy for rural labour force).

Table (1): Data description, measurement and sources

Symbol	**Variable description and measurement**	**Data Sources**
Dependent variable		
AGR	Agriculture value added (constant 2015 US $)	WDI
Explanatory variables		
A. Climactic variables		
$CO2$	Carbon dioxide emissions (Tons per capita)	British Petroleum. Statistical Review of World Energy
$TEMP$	Average annual temperature (C^0)	WDI
RF	Average annual rainfall (mm)	WDI
B. Non-climatic variables		
FC	Fertilizers consumption (kilograms per hectare of arable land)	WDI
ENC	Energy consumption (Primary energy consumption per capita)	British Petroleum. Statistical Review of World Energy.
$RPOP$	Rural population (% of total population)	WDI
CRD	Credit to the agriculture sector (millions of Egyptian pounds)	Central Bank of Egypt

The ARDL model is superior to other cointegration methods as it avoids the endogeneity problems and the inability to test hypotheses on the estimated long-run coefficients associated with the Engle-Granger method. Moreover, the long and short-run coefficients of the model are estimated simultaneously. Furthermore, the ARDL bounds testing approach to contigration could be applied regardless of whether the underlying variables are stationary I(0), integrated of order one, i.e., I(1), or a mix of I(0) and I(1). Following the existing literature (e.g. Chandio et al., 2020; Chandio et al., 2022), a natural logarithmic transformation is applied to all variables, implying that estimated coefficients represent elasticities of agricultural output in response to changes in the employed independent variables. To examine the long-run association between employed variables, equation (1) represents the specification of ARDL model. In this equation, α_0 represents the intercept, m indicates the lag order, Δ denotes the first difference operator, and ε_t is the white noise error term. LAGR, LCO2, LCRD, LTEMP, LFC, LRF; LRPOP, and LENC stand for, respectively, the natural logarithm of agriculture value added, the natural logarithm of emission of carbon dioxide, the natural logarithm of credit to agriculture sector, the natural logarithm of average temperature, the natural logarithm of the fertilizers consumption, the natural logarithm of average rainfall, the natural logarithm of rural population, and the natural logarithm of energy consumption.

$$\Delta LAGR_t = \alpha_0 + \sum_{i=1}^{m} \alpha_{1i} \Delta LCO2_{t-i} + \sum_{i=1}^{m} \alpha_{2i} \Delta LFC_{t-i} + \sum_{i=1}^{m} \alpha_{3i} \Delta LRPOP_{t-i} + \sum_{i=1}^{m} \alpha_{4i}\, L\Delta CRD_{t-i} + \sum_{i=1}^{m} \alpha_{5i} \Delta LENC_{t-i} + \sum_{i=1}^{m} \alpha_{6i} \Delta LTEMP_{t-i} + + \sum_{i=1}^{m} \alpha_{7i} \Delta LRF_{t-i} + + \beta_1 LCO2_{t-1} + \beta_2 LFC_{t-1} + \beta_3 LRPOP_{t-1} + \beta_4 LCRD_{t-1} + \beta_5 LEC_{t-1} + \beta_6 LTEMP_{t-1} + \beta_7 LRF_{t-1} + \varepsilon_t \qquad (1)$$

The bounds testing is the first stage of the ARDL cointegration method, and it is based on the F or Wald statistics. Using equation (1), the null hypothesis of no cointegration (i.e., H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = \beta_7 = 0$), is tested against the alternative hypothesis (H_1: $\beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq \beta_6 \neq \beta_7 \neq 0$). Given that the F-test used for this procedure has a non-standard distribution, Pesaran et al. (2001) introduce two sets of critical values for different significance levels, with and without a time trend. The first set of critical values assumes that all variables are stationary whereas the second set assumes that all variables are integrated of order 1. If the computed F-statistic is above the upper critical bounds value, the null hypothesis of no cointegration amongst LAGR, LCO2, LCRD, LTEMP, LFC, LRF, LRPOP, and LENC is to be rejected. In contrast, if the computed F-statistic is less than the lower critical bounds value, the null hypothesis of no cointegration amongst these variables could not be rejected. Finally, the test becomes inconclusive if the calculated F-statistic falls into the bounds. Once the bounds test confirms the existence of a long-run link amongst employed variables, the second step involves investigating the short-run dynamics. Thus, the error correction model is expressed in equation (2). In this equation, EC_{t-1} represents the error correction term resulting from the estimated cointegration model whereas λ is the speed of adjustment coefficient such that $-1 < \lambda < 0$ and.

$$\Delta LAGR_t = \alpha_0 + + \sum_{i=1}^{m} \alpha_{1i} \Delta LCO2_{t-i} + \sum_{i=1}^{m} \alpha_{2i} \Delta LFC_{t-i} + \sum_{i=1}^{m} \alpha_{3i} \Delta LRPOP_{t-i} + \sum_{i=1}^{m} \alpha_{4i} \Delta LCRD_{t-i} + \sum_{i=1}^{m} \alpha_{5i} \Delta LENC_{t-i} + \sum_{i=1}^{m} \alpha_{6i} \Delta LTEMP_{t-i} + + \sum_{i=1}^{m} \alpha_{7i} \Delta LRF_{t-i} + \lambda EC_{t-1} + \epsilon_t \qquad (2)$$

Bahmani-Oskooee and Chomsisengphet (2002) claimed that the cointegration relation obtained from equation (2) does not necessarily indicate the stability of the estimated coefficients. Thus, the cumulative sum of recursive residual (CUSUM) and the sum of squares of recursive residuals (CUSUMSQ) tests are employed to test for model constancy. These tests are based on the recursive regression of Brown et al. (1975). In this method, the two statistics are updated recursively and plotted against the breakpoints of the model. If the plots of these statistics fall inside the critical bounds of 5% significance, then we can conclude that the regression coefficients are stable.

5. Empirical Results and Discussion:

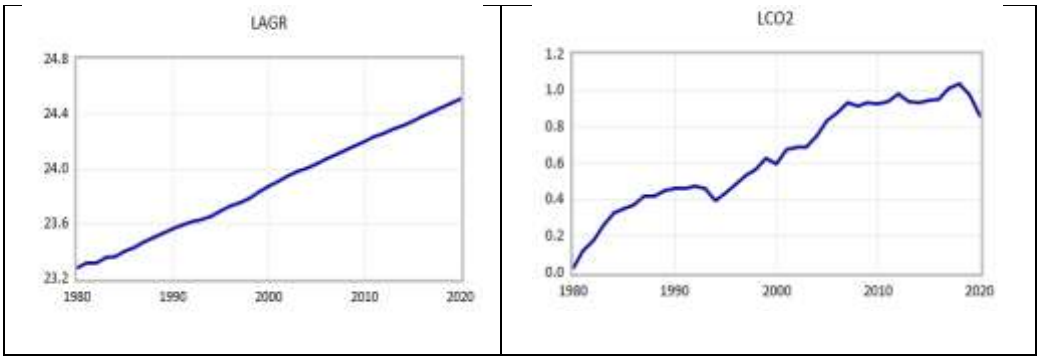
The current section starts with introducing the preliminary analysis of the employed data which include data visualization, descriptive statistical analysis, and unit root tests to investigate for the individual order of integration of series under consideration. The study uses the non-parametric Phillips–Perron (PP) unit root test developed by Phillips and Perron (1988) to control for higher order autocorrelation in a series, to check stationarity properties of the study variables. After examining the integrating order of the employed variables, the section proceeds to examine the existence of long-run equilibrium relationship amongst them using the ARDL bounds testing approach to cointegration. This is followed by estimating the error-correction model that shows the relationship between employed variables in the short run.

5.1 **Preliminary Analysis**

Figure (6) displays the time plots of natural logarithm of the employed variables over the study period. Plotting the data series provides an initial clue and intuitive feel about the properties of time series data. It seems that all employed variables, with the exception of the natural logarithm of the rainfall and the natural logarithm of temperature, are non-stationary in levels. However, concentrate unit root tests have to be executed to determine their stationarity properties. Table (2) displays the descriptive statistics of the natural logarithm of the employed variables. According to the Jaque-Bera test statistics and its accompanied p-values, all employed variables are likely to be withdrawn from a normal distribution since the null hypothesis that the series of interest follows a normal distribution could not be rejected at any conventional level of significance.

The unconditional standard deviation of a variable provides some idea of how much it varied over the study period. Taking into consideration that all variables are expressed in a natural logarithmic form, it is possible to compare the degree of variation across employed variables. It is clear that rural population as a percentage of labour force, a proxy for rural labour force, has the lowest variation (0.007), followed by the average annual temperature (0.026). In contrast, credit provided to the agriculture sector has the highest variability amongst employed variables (0.898) which is followed by the agriculture value added (0.378) and energy consumption (0.215). Furthermore, the remaining variables have approximately the same variation over the period under examination.

Figure (6): Time plots of natural logarithm of employed variables



Notes: LAGR, LCO2, LCRD, LTEMP, LFC, LRF; LRPOP, and LENC stand for, respectively, the natural logarithm of agriculture value added, the natural logarithm of emission of carbon dioxide, the natural logarithm of credit to agriculture sector, the natural logarithm of average temperature, the natural logarithm of the fertilizers consumption, the natural logarithm of average rainfall, the natural logarithm of rural population, and the natural logarithm of energy consumption. **Source**: Authors' calculations based on EViews 12.

Table (2): Descriptive Statistics of natural logarithm of variables under consideration

Stats	*LAGR*	*LCO2*	*LFC*	*LRF*	*LRPOP*	*LEC*	*LTEMP*	*LCRD*
Mean	23.87449	0.518575	6.093364	3.007383	4.040409	3.350872	3.131042	8.639529
Median	23.870	0.498193	6.108677	2.987700	4.043051	3.356897	3.135059	8.684401
Max.	24.50682	0.782622	6.397060	3.318178	4.049033	3.650658	3.201119	10.41024
Min.	23.27487	0.033680	5.670725	2.693275	4.026173	2.856470	3.072230	6.144186
Std. Dev.	0.378362	0.188043	0.186881	0.171748	0.007842	0.215294	0.026379	0.898456
Skewness	0.039686	-0.300454	-0.359411	0.085746	-0.810008	-0.195916	0.145811	-0.701737
Kurtosis	1.731039	2.463824	2.375879	2.271303	2.107107	1.961959	3.178617	3.787791
Jarque-Bera	2.761627	1.107980	1.548145	0.957365	5.845422	2.103063	0.199786	4.425186
P- value	0.251374	0.574652	0.461131	0.619599	0.053788	0.349402	0.904934	0.109417

Observations	41	41	41	41	41	41	41	41
Source: Authors' calculations based on EViews 12.								

Table (3) shows the results of Phillip-Perron unit root test of all employed variables. Some variables, including the dependent variable, are individually integrated of order one (i.e., I(1)) and, thus, they are stationary at their first difference. The natural logarithm of average temperature and the natural logarithm of average rainfall are stationary at level (integrated of order zero, i.e., I(0)). Such findings validate using the ARDL bounds testing approach to cointegration to investigate the long run link amongst employed variables.

Table (3): Results of Phillip-Perron (PP) unit root test

Variable	Test Statistic	Decision
$LAGR_t$	-2.810 (C&N) [0.202]	$LAGR_t \sim (1)$
$\Delta LAGR_t$	-7.379 (C) [0.000]*	
$LCO2_t$	-2.526 (C) [0.116]	$LCO2_t \sim (1)$
$\Delta LCO2_t$	-3.996 (C) [0.006]*	
$LCRD_t$	-2.161 (C) [0.223]	$LCRD_t \sim (1)$
$L\Delta CRD_t$	-6.214 (C) [0.000]*	
LFC_t	-2.463 (C) [0.131]	$LFC_t \sim (1)$
ΔLFC_t	-7.521 (C) [0.000]*	
LRF_t	-5.613 (C) [0.000]*	$LRF_t \sim (0)$
$LRPOP_t$	-1.431 (C) [0.557]	$LRPOP_t \sim (1)]$
$\Delta LRPOP_t$	-1.709 (N) [0.08]***	
$LTEMP_t$	-2.992 (C) [0.044]**	$LTEMP_t \sim (0)$
$LENC_t$	-2.810 (C&N) [0.202]	$LTEMP_t \sim (1)$
$\Delta LENC_t$	-2.915 (C) [0. 052]***	

Notes: (1) Letters in round brackets next to the calculated PP test statistics, i.e., C, T, and N, indicate that the test equation includes constant, trend, and non. (2) Δ is the difference operator. (3) The employed Bandwidth is determined by Newey-West automatic. (4) P-value is provided between square brackets. (5) *, **, *** indicates that the null hypothesis that the series under consideration has a unit root should be rejected at 1%, and 5% level of significance, respectively. (6) $\sim (0)$ indicates that the variable is stationary whereas $\sim(1)$ means that the variable under consideration is integrated of order one. **Source**: Authors' calculations based on EViews 12.

5.2 Long-run Relationship

Based on unit root tests, revealing that employed variables contain a mixture of I(0) and I(1) orders of integration, the ARDL bounds testing approach to cointegration is employed, and the AIC criterion established the maximum lags of 2, 1, 0, 1, 2, 2, 2, 1 for LAGR, LCO2, LRF, LTEMP, LFC, LRPOP, LCRD, LENC, respectively. Table (4) reports the results of Wald Test (F-statistic) for a long run link. The null hypothesis of no cointegration amongst employed variables is to be rejected since the computed F-statistic of 10.388 is significantly greater than the upper bound critical value of 5.464 at 1% level of significance.

Table (4): Bounds test for cointegration.

Order of dynamic regressors in ARDL: (LAGR, LCO2, LRF, LTEMP, LFC, LRPOP, LCRD, LENC) & **Selected Model Lag Structure**: ARDL (2, 1, 0, 1, 2, 2, 2, 1)				
Computed F-stat.	1% critical values		5% critical values	
	I0 Bound	I1 Bound	I0 Bound	I1 Bound
10.388*	3.644	5.464	2.676	4.13

Notes: (1) Lag length is chosen according to Akaike Information Criterion (AIC) with maximum lag length of 2. (2) The estimation allows for an unrestricted intercept and no trend (i.e., case III). (3) The critical value for ARDL bounds test is based upon Narayan (2005) table where n=40 and k=7. (4) The lag structure indicates that the selected model employs 2 lags for the dependent variable whereas lags of 1, zero, 1, 2, 2, 2, and 1 are assigned to the dynamic regressors, LCO2, LRF, LTEMP, LFC, LRPOP, LCRD, and LENC, respectively. (5) * indicates the rejection of the null hypothesis of the absence of cointegrating relationship at 1% level of significance. **Source**: Authors' calculations

Table (5) presents the results of the ARDL model. Panel A of the table exhibits the results of the long-run relationship between the employed variables whereas Panel B displays the short-run estimation. Panel C of the aforementioned table shows the post-estimation model diagnosis. The estimated model has successfully passed several diagnostic tests where residuals are found to be free from serial autocorrelation and heteroscedisticity. Moreover, residuals are likely to be withdrawn from a normal distribution. The Ramsey RESET test for model specification shows the absence of misspecifications. Thus, the estimated model exhibits no significant departure from the standard assumptions. Furthermore, the estimated model is found to be stable since CUSUM and CUSUMSQ test statistics fall within the critical bounds of 5% significance as depicted in Figure 7.

Regarding the impact of climatic factors on the agrarian output, results show that CO2 emissions have a significant and negative long-run impact on it at 5% level of significance, implying that a 1% increase in CO2 emissions per capita will lead to a %3.72 decrease in it. Such conclusion confirms the conclusions of Agba et al. (2017) and Sibanda & Ndlela (2019) who found that CO2 emissions have significant and adverse long-run effects on agricultural output in Nigeria and South Africa, respectively. This could be explained by the fact that the consumption of toxic CO2 emissions by vegetation can negatively impact plant quality, aesthetics, and economic value. When CO2 sinks in the atmosphere, it can harm vegetation and aquatic life, causing harm to both plants and aquatic life.

With respect to temperature, the estimated long-run coefficient is found to be significant, at 10% level of significance, and positive implying that an increase of average annual temperature by 1% results in a rise of the Egyptian agricultural value added by 2.962%. This result is in line with the conclusion of Dumrul & Kilicarslan (2017) who detected a positive and significant long-run effects of temperature on the Turkish agricultural output. However, other studies, e.g., Chandio et al. (2020), showed that temperature has a negative impact on Chinese agricultural output in the long run and Mubenga-Tshitaka et al., (2023) concluded that, on average, temperature and temperature variability have a negative and significant long-run effects on agricultural output in East Africa. These conclusions can be attributed to the fact that different crops require specific temperatures for optimal growth and development. CG may cause earlier crop growth and a squeeze of growing seasons, helping some crops escape summer drought stress. However, increased extreme weather events like heat waves and frost can cause bud breaks, affecting the final quality and quantity of yields. Studies conducted using Egyptian data indicated that productivity of many crops (including wheat, rice and maize) will be negatively affected by the increasing temperature whereas other crops such as cotton and potato are likely to benefit from warmer temperatures[1] (Mahmoud, 2019).

Regarding the long-run impact of rainfall on the Egyptian agriculture output, it is found to be negative but insignificant at any conventional level of significance. This is not surprising, as mentioned earlier, because the Egyptian agriculture heavily depends upon irrigation from the River Nile where over 80% of Egypt's water supply is used in agriculture. It is worth mentioning that the availability of water in Egypt is expected to be significantly influenced by changes in the Nile Basin's temperature, evapotranspiration, and precipitation brought on by climate change (World Bank, 2022).

The coefficients of non-climatic variables (i.e., energy consumption, rural population, fertilizer use, and credit to agriculture sector) are found to be significant and positive in the long-run. These results are in line with the findings of Faridi & Murtaza (2013), Sial et al (2011), Ahmad et al., (2018), Chandio et al. (2022) and Zou (2022). Our empirical findings reveal that a 1% increase in fertilizer use would result in 1.3% rise in the agriculture output in the long run. Fertilisers can play a key role in mitigating any negative long-term effects on agricultural productivity. The appropriate use of fertilisers might enhance soil fertility and nutrition (Chandio et al., 2022). A 1% rise in credit to agriculture sector causes agriculture value added to increase by around 0.26%. The provision of sufficient credit is crucial for the availability of agricultural inputs such as seeds, fertilizers, pesticides, and mechanization of farm activities as confirmed by other scholars (e.g., Sial et al., 2011; Ahmad et al., 2018).

In the early 1990s, villages in Egypt lacked banks, leading to the Principal Bank for Development and Agricultural Credit becoming a monopoly with around 900 banking units. As a result, informal finance became a popular financial arrangement for many rural firms and households. Informal finance, particularly rotating savings and credit associations, is a popular and widely used form of financial assistance in Egypt. These groups are self-help financial groups that address various financial needs. Each member contributes a share to a pot, and funds are distributed to members in turn. This form of finance relies on mutual trust and mutual interest within the group. Village savings and loan associations use the core structure of rotating savings and credit associations, adding greater flexibility and accountability. Accumulating savings and credit associations allow savings to be accumulated rather than redistributed instantly, with a member appointed to manage an internal fund. Despite limited access to formal financial institutions, many Egyptians still prefer informal finance due to its unique features, such as flexibility, lower transaction costs, resolving problems with asymmetric information and agency directly, and consistency with Islamic laws on interest payments (Emara et al., 2022).

Our empirical results show that a rise in energy consumption (a proxy for mechanisation) by 1% causes the agricultural output to rise by around 4%. Energy consumption in agriculture is essential for the expansion of mechanisation. Agricultural mechanisation is required to maximise farm productivity and operating efficiency. Furthermore, increasing agricultural output is not feasible without making appropriate use of machines. Smallholder farmers in developing countries often lack the means to fully mechanise their farming operations. Therefore, equipment rental services, which support farm income and food security, can be used to fully mechanise all agricultural processes. In Egypt, some small-scale farmers use rental agricultural mechanization. However, there is still a shortage of agricultural machinery rental centers (Sayed et al., 2023). An increase of 1% in rural population to total population (a proxy of the labour force in agriculture sector) causes the agricultural output to rise by around 13%. Egypt's agriculture is still heavily labour-intensive, with average increases in labour productivity over the past 10 years only amounting to 1% in terms of agriculture value added per worker in constant US Dollar (Tellioglu & Konandreas, 2017).

Kirui (2019) explores the status, drivers, and impacts of agricultural mechanization in eleven African countries, including Egypt. African farming systems are the least mechanized in the world, largely due to factors such as market failures, missing institutions, and governance challenges. Additionally, political interest, elite capture, ineptness, and corruption constrain the government and hinder private sector involvement in machinery importation. Factors driving mechanization include household size, gender, participation in off-farm activities, distance to markets, farm size, land tenure, farming system, extension services, and fertilizer and pesticide use.

Table (5): Results of ARDL model

Order of dynamic regressors in ARDL: (LAGR, LCO2, LRF, LTEMP, LFC, LRPOP, LCRD, LENC) **Selected Model**: ARDL (2, 1, 0, 1, 2, 2, 2, 1)

Panel A: Long-run elasticities: Dependent variable: $LAGR_t$		
Regressors	Coef.	*p*-value
$LCO2_t$	-3.725	0.012**
LRF_t	-0.0342	0.689
$LTEMP_t$	2.962	0.054***
LFC_t	1.315	0.016**
$LRPOP_t$	13.066	0.056***
$LCRD_t$	0.2678	0.003*
$LENC_t$	4.009	0.003*
Panel B: Short-term elasticities: $\Delta LAGR_t$		
Intercept	-2.772	0.000*
$\Delta LAGR_{t-1}$	-0.6272	0.000*
$\Delta LCO2_t$	-0.1035	0.000*

Table (5): Results of ARDL model		
$\Delta LTEMP_t$	0.06071	0.037**
ΔLFC_t	-0.0039	0.587
ΔLFC_{t-1}	-0.04288	0.000*
$\Delta LRPOP_t$	5.0061	0.000*
$\Delta LRPOP_{t-1}$	-7.9748	0.000*
$\Delta LCRD_t$	0.00546	0.041**
$\Delta LCRD_{t-1}$	-0.0050	0.026**
$\Delta LENC_t$	0.0408	0.162
ECT_{t-1}	-0.0473	0.000*
Panel C: Diagnostic tests		
R^2 $\bar{R}_2$	0.847 0.784	0.000 (p-value of F-stat)
Heteroscedasticity ARCH LM: $\chi^2(2)$ Heteroscedasticity Breusch-Pagan-Godfrey $\chi^2(18)$	2.520 9.255	0.283 0.953
Normality Jarque-Bera Test: $\chi^2(2)$	0.320	0.852
Breusch-Godfrey Test Serial correlation LM test: $F_{(1,19)}$ $F_{(13,7)}$	0.724 2.298	0.405 0.136
Ramsey RESET Test $F_{(1,19)}$	2.258	0.149
Stability tests CUSUM test CUSUMSQ test	 Stable Stable	 Refer to Figure 7 Refer to Figure 7

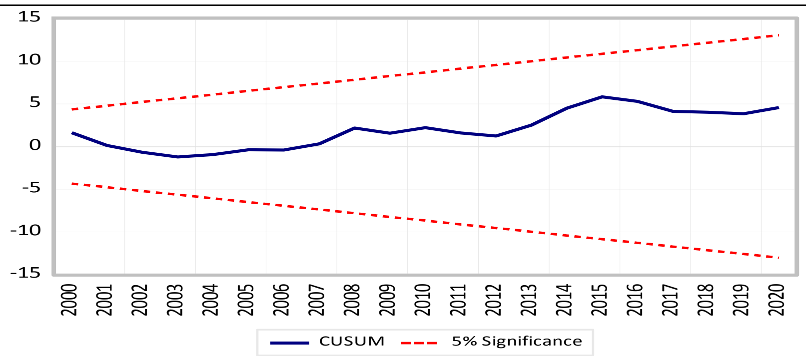
Notes: *, ** indicates significance at 1%, and 5% level of significance.

Source: Authors' calculations based on EViews 12.

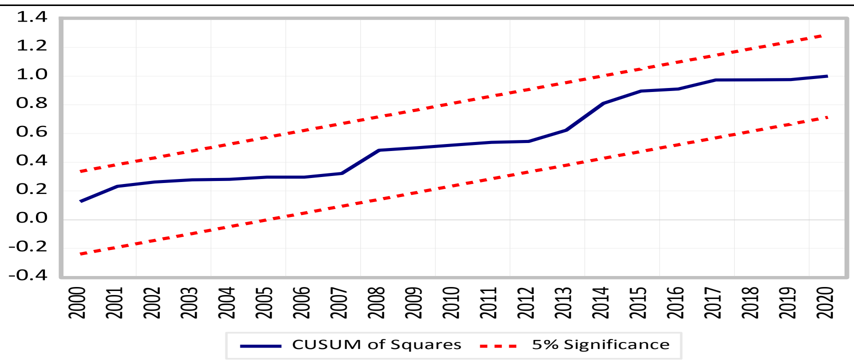
The study of Kirui (2019) found that light hand-held tools and equipment are the main type of machinery in most countries, with 48% of surveyed households having access to these tools. Animal-powered machinery is the main type in Senegal, Burkina Faso, and Zimbabwe, while tractor-powered machinery is largely common in more developed African countries like Egypt and South Africa. Machinery can be acquired through ownership by a single household, joint ownership with other households, or leasing. Light machinery and animal-powered machinery are mainly owned by individual households, with a few households renting medium-to-heavy machinery like tractors, ploughs, and threshers. Moreover, the study reveals that agricultural mechanization significantly increases cropland cultivation by 7ha and 51ha for animal-powered and tractor-powered mechanization, respectively. It also showed that both types of mechanization impact household and hired labor usage. Animal-powered mechanization increases household labor by 2 adult equivalents and the probability of using hired labour by 20%, while tractor-powered mechanization reduces household labour by 1.6 adult equivalents and the probability of using hired labour by 16%. The study also revealed that animal-powered mechanization increases maize and rice yields by 98kg/ha and 362kg/ha, while tractor-powered mechanization increases them by 487kg/ha and 677kg/ha, respectively. In addition, mechanisation facilitates the timely preparation of land and the cultivation of land that would not have been feasible otherwise because of seasonal labour shortages.

Figure (7): Stability tests

Panel 1: Plot of Cumulative Sum of Recursive Residuals (CUSUM)



Panel 2: Plot of Cumulative Sum of Squares of Recursive Residuals (CUSUMSQ)



Source: Authors' calculations based on EViews 12.

5.3. Short-run estimates

The estimates of short-run dynamics and the error correction term are shown in Table 5 (Panel B). The error-correction term is −0.0473 with the expected sign, suggesting that about 5% of any deviation from equilibrium are corrected for within the same year (i.e., the full convergence process to its equilibrium level takes around 12 years). As expected, all estimated short-run coefficients are lower than their long-run counterparts. In line with the results of Edoja et al. (2016), our findings indicate that an increase of CO_2 emissions by 1% results in a decline of agriculture output by around 0.103% in the short run. Whereas the agricultural output increases by around 0.06% in response to a rise in the average temperature by 1% in the short run. The impact of energy consumption is positive but not significant in the short-run. Our findings reveal that fertilizers consumption has a negative and significant impact on agrarian value added in the short run. According to Krasilnikov et al. (2022), excess usage of chemical fertilizers can change soil pH, raise pest attacks, acidification, and soil crust, decreasing soil organic carbon and useful organisms and ultimately restricting plant growth and yield. Furthermore, improper fertilizing technology may also lead to increasing the emission of greenhouse gases. Egypt's government subsidizes nitrogen fertilizer directly and indirectly to ensure food self-sufficiency in strategic crops. A survey of smallholder farmers in Upper Egypt, conducted by Kurdi et al. (2020), revealed that application rates of nitrogen fertilizer are significantly above crop-specific agronomic recommendations. Farm plots with easier access to the subsidy use more subsidized nitrogen fertilizer and less phosphate fertilizer. This overapplication of fertilizer negatively affects soil, water, and environmental health.

In the short run, the coefficients of agriculture credit have significant impacts on agrarian production with mixed signs. The one-period lagged agriculture credit, i.e., $\Delta LCRD_t$ has a positive and significant influence on agrarian output whereas the two-period lagged agriculture credit, i.e., $\Delta LCRD_{t-1}$, has a negative and significant influence on agricultural output. This conclusion is in line with results of Rehman et al., (2017) who reached mixed conclusions regarding the impact of agricultural credit on agricultural output in Pakistan over the period 1960-2015. Financial constraints in developing economies contribute to backwardness, negatively impacting agricultural output and farmer income. In Egypt, smallholder farmers face many challenges, including, lack of rural finance mainly due to land fragmentation. The majority of smallholder farmers own small plots of land, and thus, they lack collateral for credit access and struggle to access credit whereas land in the reclaimed 'new' lands is owned by the state (Chen, 2020).

Concerning the short-run impact of rural population as percentage of total population, a proxy of rural labour, the two-period lagged coefficient, i.e. the coefficient of $\Delta LRPOP_{t-1}$, has a significant and negative impact on agrarian output which disagree with prior theoretical expectations. This result is in line with findings of Otim et al., (2023) who detect a negative and significant short-run impact of labour on crop production index for East African Community countries which could be explained by the fact that the marginal product of labour in the agricultural sector is zero, meaning that increasing labour further without supplementing it with capital and skill will inevitably result in decreased production. Moreover, this could be explained by the fact the increasing percent of rural population to total population in Egypt in the recent period, starting from 2010 as shown in Figure 6, was accompanied by a rapid pace of urbanisation in recent decades, primarily due to changes in the use of agricultural land in rural areas. Egypt's high rate of urban sprawl results in the loss of approximately 30,000 hectares of prime agricultural land each year as a result of uncontrolled urban growth. Political instability, emerged in January 2011, led to unprecedented urban sprawl in Egypt, resulting in large-scale encroachments and a loss of around 1% of the country's total cultivated area between 2010 and 2011. Thus, the per capita agricultural land area declined from 0.48 ha in 1907 to 0.14 ha in 1996 and continued to fall to 0.03 ha by 2016 (Salem, 2020; Abu Hatab et al., 2022).

6. Conclusion, policy implications, limitations and areas for further research

The CG imposes a significant threat to agriculture in Egypt, with implications for food security, rural livelihoods, and the overall economy. The study aims to empirically examine the long and short-run impacts of climatic variables (i.e., CO2 emissions, average temperature, and average rainfall) on the agricultural output in Egypt over the period extending from 1980 to 2020. Non-climatic variables (i.e., energy consumption, fertilizers usage, the percentage of rural population to total population as a proxy of rural labour force, and domestic credit to the agriculture sector) are used as control variables. To check the stationarity properties of employed variables, Phillips–Perron unit root tests were employed confirming that some variables are stationary at level whereas other variables, including the dependent variable, are individually integrated of order one. Accordingly, the ARDL bounds testing approach to cointegration of Pesaran et al., (2001) was applied onto annual data over 1980-2020.

Results of the ARDL model reveals that there exists a long-run equilibrium link between the Egyptian agriculture output and employed explanatory variables. Climatic variables, excluding rainfall, have significant long-run impacts on the Egyptian agrarian output. In the long run, a 1% rise in per capita CO2 emissions leads to a %3.72 drop in agriculture output which is consistent with previous studies in Nigeria and South Africa. The consumption of toxic CO2 emissions by vegetation can negatively impact plant quality, aesthetics, and economic value. On the other hand, an increase of average annual temperature by 1% results in a rise of the Egyptian agricultural value added by 2.962% in the long run. This aligns with previous studies showing positive long-run effects of temperature on Turkish agricultural output. However, other studies showed that temperature has a negative long-run effect on Chinese agricultural output and East African agricultural output. CG change can cause earlier crop growth and a squeeze of growing seasons, helping some crops escape summer drought stress. However, extreme weather events like heat waves and frost can cause bud breaks, affecting yield quality and quantity. The long-term impact of rainfall on Egyptian agriculture output is negative but insignificant, as irrigation relies heavily on the Nile River, which supplies over 80% of Egypt's water supply. Climate change-induced temperature, evapotranspiration, and precipitation changes could significantly influence water availability. The long-term effects of non-climatic variables on agriculture output are significant and positive. A 1% increase in fertilizer use can lead to a 1.3% increase in agriculture output, while a 1% rise in credit to the agriculture sector can increase agriculture value added by around 0.26%. Moreover, a 1% increase in energy consumption leads to a 4% increase in agricultural output in the long run. Similarly, an increase in rural population in Egypt leads to a 13% rise in agricultural output.

With respect to short-run dynamics, the error-correction term has the expected negative sign indicating that around 5% of any deviation from equilibrium are corrected for within the same year. Short-run coefficients are lower than their long-run counterparts. An increase in CO2 emissions leads to a decline in agriculture output by 0.103% in the short run, while a rise in average temperature increases output by 0.06%. Energy consumption has positive but insignificant short-run effect on agrarian value added. Fertilizer consumption has a short-run negative impact on agrarian value added, as excess usage can negatively influence the soil. The impact of agriculture credit on agrarian production is mixed, with one-period lagged agriculture credit having a positive effect and two-period lagged agriculture credit having a negative impact. This is consistent with previous studies in Pakistan. Financial constraints in developing economies contribute to backwardness, negatively impacting agricultural output and farmer income. In Egypt, smallholder farmers face challenges like lack of rural finance due to land fragmentation. The two-period lagged coefficient of rural population as percentage of total population has a significant negative impact on agrarian output. The increasing proportion of rural population in Egypt has led to rapid urbanization, causing the loss of 30,000 hectares of prime agricultural land annually. Political instability in 2011 caused unprecedented urban sprawl, leading to large-scale encroachments and a loss of around 1% of the country's total cultivated area. As a result, the per capita agricultural land area declined from 0.48 ha in 1907 to 0.03 ha by 2016.

Based on our empirical and analytical findings, the current paper has many policy implications. Strict regulation of carbon emissions should be imposed given that these emissions negatively impact on the Egyptian agrarian output in short and long runs. Carbon emissions can be mitigated by implementing policies such as carbon taxes, increasing renewable energy consumption, sustainable farming practices, and organic manure. Furthermore, global collaboration is required to mitigate greenhouse gas emissions, considering the enormous cost to Egypt's society of the negative effects of CG around the world. Given the issue of water scarcity in Egypt and that rainfall is mostly limited to the northern coastal region, it is highly recommended to install a rain-harvesting system in the Mediterranean coastal region. Taking into consideration the indirect effect of CG on agricultural production (e.g., crop pests, higher temperatures that reduces yields for many crops, water supply, and irrigation) and challenges facing the Egyptian agriculture (i.e., the construction of the GERD on the Nile River), it is of crucial importance to develop crops that are resistant to heat, drought, salinity and stress-tolerant. In addition, more efficient use of water resources (e.g., implementing efficient irrigation techniques such as subsurface drip irrigation and sprinkler irrigation) is highly recommended. Moreover, using treated wastewater in the agriculture is likely to be a reliable approach for overcoming water scarcity and sustaining water resources in Egypt. Additional agricultural adaptation methods include mixed crop and livestock farming systems and changes in agricultural activity dates.

Due to the positive impact of credit on the agrarian output and given that rural areas suffer from limited access to formal financial institutions, the Egyptian government should establish and implement new credit schemes to rural agricultural centers. These new funding schemes have to consider that smallholder farmers in old land face difficulty accessing credit due to lack of collateral and land fragmentation. Furthermore, the banking system should ensure the adequate expansion of its loans to the agrarian sector at low-interest rates for smooth flow of inputs (e.g., seeds and fertilizers). Results indicate that agricultural output is driven by energy consumption (a proxy for mechanisation), and, thus shortfall of energy supply are likely to negatively impact on agricultural output. For this reason, ensuring sufficient energy supply is necessary to boost agrarian production.

However, traditional diesel-powered agricultural machinery emits high carbon emissions, necessitating the development of new energy agricultural machinery and technological innovation for low-carbon mechanization. A recent study conducted by Abo-Habaga et al. (2021) about energy used for irrigation in the new reclamation lands in Egypt revealed that solar photovoltaic panels have a higher initial cost compared to diesel systems, however, the recurring cost of solar energy is lower implying that solar photovoltaic panels can be a cost-competitive alternative to diesel systems. Accordingly, efforts should be made to promote the usage of renewable energy or to advance the technology employed when nonrenewable energy is employed with the goal of limiting environmental deterioration in agriculture while maintaining income and boosting ecoefficiency within sustainable practices.

The overuse of subsidised fertilizers with potentially negative impacts on agricultural value added indicates considerable resources misallocation. Hence, the Egyptian government is advised to reform the fertilizer subsidy system while maintaining agricultural productivity. Also, farmers may reallocate funds spent on fertilizer without affecting agricultural yields. In order to encourage farmers to apply optimal levels of fertilizers, the government may also adopt smart instruments and technologies and pay more attention to raise farmers' awareness regarding the adequate use of fertilizers. Given the economic costs of large-scale encroachments on agrarian land, enforcing strict regulations are of crucial importance.

According to Perez et al (2021), climate change impacts on Egypt's agriculture could cost $55.3 billion over the period 2020-2050, requiring cost-effective adaptation investments to reduce net import bills and food insecurity risks. It is worth mentioning that the biggest challenge facing Egypt's adaptation to CG in agriculture is not science or planning-based, but rather successful implementation. While strategies exist, their implementation has been the primary problem. The current study recommends the policy interventions proposed by Barakat et al., (2022) that allows the government to effectively and efficiently implement its agricultural adaptation plans. The first policy intervention is s farmer-centric strategy. It is based on establishing oriented-partnership between Egyptian Ministries of International Cooperation and Environment and the European Union in which a framework for technology transfer, capacity building, and knowledge exchange on Climate Change Adaptation and Early Warning Systems in Agriculture is implemented. The second policy intervention is to create a climate funding and resource mobilisation unit within the Ministry of Environment, with a focus on agricultural adaptation finance. The proposed unit should promote responsible finance mechanisms to fill funding shortages in the agricultural sector at the national and farmer levels. The third policy intervention is to support local market linkages and value chains in addition to eliminating post-harvest agricultural losses and food waste.

Limitations of the current study include using the aggregate agricultural output. Hence, further area of research may explore the impact of climatic factors on disaggregate agricultural output (e.g., crops, livestock, poultry, and fishery). Another limitation of the current study is using CO2 emissions and ignoring other greenhouse emissions. Thus, another area of further research is studying the effects of climate change variables and other greenhouse gases (e.g., methane) on crop output and livestock production in Egypt and other countries employing regional-specific and crop-specific datasets. Also, the current study is limited by using average temperature and average precipitation as climatic factors affecting agrarian output in Egypt. Accordingly, future studies can address the impact of climatic factors variability on the agricultural value added in Egypt and other countries. Additional limitation of the current research is the exclusion of some important non-climate factors such as investment and the global prices of food and energy. Adding more variables to the model reduces the degree of freedom available for parameter estimation, potentially leading to bad estimates. Moreover, the inclusion of non-climatic variables is likely to alter the focus of this study away from the impact of key climate variables on the agricultural value added. Thus, future research should address these issues as follows. To overcome the issue of degrees of freedom loss, longer time series datasets or panel data should be employed. Moreover, alternative models with different control variables should be used to enable inter-modeling comparisons of the effects of non-climate factors on agricultural output. Finally, since literature identifies agriculture as a source of greenhouse gases, a further area of research might be investigating the impact of different components of agricultural output (e.g., crops and livestock) on greenhouse gases, including CO2 and methane emissions.

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