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REVIEW

The interplay between agriculture, greenhouse gases, and climate change in Sub-Saharan Africa

Abeeb Babatunde Omotoso[1] · **Abiodun Olusola Omotayo**[1,2]

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Abstract

Agriculture is the leading sector that is responsible for global climate change through its significant contribution to greenhouse gas (GHG) emissions. Intriguingly, sub-Saharan Africa (SSA) is experiencing higher temperatures and lesser rainfall due to climate change enhanced by anthropogenic GHG emissions. Agriculture and energy use in the SSA predominantly influence the anthropogenic GHG leading to global warming. Therefore, reducing agricultural GHG emissions (such as carbon dioxide, nitrous oxide, and methane) plays a significant role in climate change adaptation. This paper reviews the potential implication of agriculture and energy use on climate change and its implications on environmental sustainability in SSA. Herewith, we explored various GHGs emitted through agriculture-energy use, their effects on climate change, as well as several climate change adaptation mechanisms, and gaps in existing knowledge that necessitate more research, were also explored. We found that agriculture had negative implications on climate change impacts in the SSA countries and that a more focused strategy that is both economically and technically feasible in terms of preferences for land use, effective energy use, and food supply would aid in GHG emission reduction and environmental sustainability. Adapting to the projected changes in the short term while investing in long-term mitigation strategies might be the only way toward a sustainable environment in this region.

Keywords Energy use · Climate-smart practices · Global warming · Land use · Sustainability · Urban agriculture

Introduction

Human-induced climate change is a significant environmental issue that affects people all around the world with its implications cutting across a variety of different industries, ranging from the energy sector to the health industry and the agricultural industry (Scott et al. 2023; Tongwane and Moeletsi 2018). The world's climate is getting warmer and various studies (Chabbi et al. 2017; Outhwaite et al. 2022) confirmed that it is due to various human activities emitting planet-warming gases, called greenhouse gases (GHGs). GHGs such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are emitted by a variety of human activities, including deforestation, disrupting the natural use of land, industrial operations, unsustainable agriculture (such as excessive application of pesticide and fertilizer), and the use of fossil fuels such as coal, oil, and petroleum products (Borrelli et al. 2020; Scott et al. 2023).

Regrettably, a continuous increase in GHG concentration across the globe creates the greenhouse effect, which leads to global warming and climate change (Gopalakrishnan et al. 2019; Tongwane and Moeletsi 2018). Globally, there is a 75% increment in GHG emissions in the last 30 years (Chabbi et al. 2017; Outhwaite et al. 2022). Assessing the present total source of GHGs, carbon dioxide (CO_2) contributes about 76%; methane (CH_4) is around 16%, while nitrous oxide (N_2O) is around 6% (Crippa et al. 2021). The synergy between GHG emissions and human activities (like agriculture, fossil fuel burning, and energy use) is crucial and well known to people (Lungarska and Chakir 2018; Rama Rao

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✉ Abiodun Olusola Omotayo
abiodunomotayo@daad-alumni.de

Abeeb Babatunde Omotoso
43120075@mynwu.ac.za

[1] Department of Agricultural Economics and Extension, Faculty of Natural and Agricultural Science, North-West University, Mahikeng, South Africa

[2] Food Security and Safety Focus Area Research Group, North-West University, Mahikeng, South Africa

et al. 2016). According to various literature (Omotoso et al. 2023; Outhwaite et al. 2022), the effects of GHG emissions on ecological and socioeconomic vulnerabilities are severe and will continue to increase regionally and globally in the coming years if human-induced activities such as agriculture and its energy use are not well managed.

In Africa, GHG emissions as a result of various human activities have grown with about 84% increment between 1970 and 2020 (Mullins et al. 2018; Robinson 2020). It is due to an increase in the global radiative force of CO_2, CH_4, and N_2O rising more rapidly presently than at any other period in the last 1000 years (Adusah-Poku 2016; Boateng et al. 2019). In SSA, climate change and agriculture are two entities that cannot be separated, which can result in negative impacts on each other if not well managed (Robinson 2020).

According to Leitner et al. (2020) and Robinson (2020), temperature changes in the SSA as a result of high continuously changing anthropogenic GHG emissions have led to increased scrutiny of the role all sectors can play in climate change adaptation, with a particular focus on agriculture. Management of agricultural land in SSA coupled with forestry and land-use changes has a significant influence on GHG concentration in the atmosphere (Praveen and Sharma 2019). The primary contributors to GHG emissions within the agricultural sector are agricultural energy consumption, including activities such as food processing and the utilization of farm inputs, as well as land use for agricultural purposes (Chalise and Naranpanawa 2016). Apart from the CO_2 emitted during crop burning and animal waste, livestock production and rice fields contribute significantly to methane emissions (Outhwaite et al. 2022). Understanding GHG emissions from agricultural sources like enteric fermentation from livestock and CO_2 emitted during energy use in farming operation is critical for developing appropriate mitigation and adaptation strategies such as sustainable farming and minimal GHGs emission from energy use in agriculture.

Intriguingly, the impact of agriculture and energy use on climate change can vary significantly depending on geographic locations, climatic conditions, agricultural practices, and energy sources adopted in farming system (Ngarava et al. 2023). Conducting context-specific studies can provide valuable insights into the unique challenges and opportunities for mitigating climate change in SSA through GHG emission reduction. While general adaptation strategies are obvious (Abernethy and Jackson 2022; Petersen et al. 2023), there is still literature gap in the evaluation of the effectiveness of adaptation practices in SSA's agriculture and energy use sector. Furthermore, there is a need for research that focus on assessing the impact, scalability, and sustainability of various adaptation measures and technologies in agriculture and energy use in SSA. This evaluation can provide insights into the success factors, challenges, and opportunities for enhancing adaptive capacity in the region.

In this paper, different agriculture and energy use influence on climate change were outlined, how their reporting could be improved was considered, as well as exploring the overall potential implications on climate change adaptation practices. The existing knowledge of the impact of agriculture and energy use on climate change is numerous in data-rich regions, such as Europe and America but inconsistence in SSA (Graham et al. 2022; Lungarska and Chakir 2018). In SSA, some research (Chalise and Naranpanawa 2016; Rama Rao et al. 2016) has been done to understand the synergy, but the findings are incoherent and disparate. This article reviews the findings of peer-reviewed studies undertaken over the last decade on the impact of agriculture and energy use on climate change and variability in the SSA.

Therefore, the paper provides an overview of the observed climate change and variability trends, as well as highlights the contribution of agricultural production and energy use to climate changes in SSA. Additionally, it identifies the adaptation strategies implemented to control GHGs emissions by farmers, outlines various policies as well as the role of institutions to support adaptations in ensuring a sustainable environment. Finally, the paper provides an overview of the state of the knowledge on the impact of GHG emissions from various land use and energy use in agriculture on climate change in SSA, highlighted the structures and trends of various GHG emissions as well as knowledge gaps, and identified priority areas for future research.

Materials and methods

Literature search

The related literature on the impact of agriculture and energy use on climate change in SSA was searched from the three accessible scholarly electronic databases (Web of Science (WoS), Scopus, and Google Scholar). These databases were used because it has an advanced search function, multidisciplinary, and scholarly quality control. Some pre-defined keywords were used to search these databases (see Table 2). The identification of keywords (such as climate change, GHG, carbon, methane, nitrogen, and urban agriculture) was first initiated for proper literature screening. To ensure that the literature used are recent and wide enough to draw reasonable conclusions, data timeline from 2000 to 2023 were used. Following Omotoso et al. (2023) and Tione et al. (2022) setting a specific time frame for data search helps maintain methodological consistency throughout the literature review. By focusing on studies published within years 2000 to 2023, this research was able to apply consistent criteria for inclusion and exclusion in order to reduce potential bias in the review process.

The full texts of the 346 articles were reviewed, from which 284 articles were discarded; this includes review articles solely concerned with contemporary agricultural practices or those where its impact on climate change was not the subject of the study. Furthermore, studies on climate change and agriculture-energy use not modeling SSA as a case study were excluded. Finally, the literature screening process reduced the results to 80 articles, representing approximately 22% of the identified literature from the database.

Systematic literature review

Systematic literature review (SLR) is the way of identifying, analyzing, and interpreting scholarly studies relevant to a research interest (Omotoso et al. 2023). This technique was adopted because of its systematic, transparent, and reproducible processes of selecting databases for the review. This study was guided by the methods outlined in the study of Omotoso et al. (2023); Pradhan et al. (2023); and Praveen and Sharma (2019). Literature was gathered from three major scientific databases [Google scholar, Scopus, and Web of Science (WoS)]. Relevant keywords and search phrases (Table 1) were used to screen out the search output. Initial information from the search of the scientific databases yielded a total of 3891 studies. Articles not published in English or published prior year 2000 were screened out. The data from the different scientific databases provided a total of 1427 studies [Scopus (517), Google scholar (95), and WoS (815)] (Appendix 1). It was discovered that searches of the bibliographic databases did not always generate material that was relevant. To focus on the most essential articles, we concentrate on agriculture and energy use to apply duplicate removal and to abstractly filter the evaluations. As such, 346 items were maintained.

The entire texts of the 346 studies were extensively scrutinized, and 170 studies were rejected, including those review articles (systematic or literary) not focusing on present agriculture and energy use impact on climate change. Furthermore, the texts of those papers not modeling SSA as case studies on climate change, variability, and agriculture were omitted. Finally, the findings of the literature screening procedure were limited to 77 articles (Appendix 2), which constituted roughly 6% of the literature identified from the database.

Agriculture and greenhouse gas emissions

The 6th assessment report of Intergovernmental Panel on Climate Change stated emphatically that a drastic approach to limit change in climate impact to 1.5 °C is needed (Kanitkar et al. 2022; Robinson 2020). This approach requires limiting the cumulative carbon budget in the atmosphere to 570 Giga tonnes of carbon dioxide ($GtCO_2$ eq/yr) by significantly reducing the emissions of other gases like nitrous oxide and methane (Leitner et al. 2020; Robinson 2020). Intriguingly, agriculture is one of the major contributors of methane (CH_4) and nitrous oxide (N_2O) (non-CO_2 GHGs), which have a greater global warming potential (Appendix 3) (Robinson 2020). In the last 20 years, about two-thirds of SSA's GHG emissions is majorly from agriculture, forestry, and land-use change (Ogunbode et al. 2020).

Likewise, the food system of SSA (crop production and livestock farming) is responsible for about 40–60% of annual emissions of GHG (Appendix 4). Also, Ogunbode et al. (2020) and Robinson (2020) reported that in 2014, agriculture in SSA comprised 15% of primary energy consumption, while in 2018, methane emissions from livestock production, carbon dioxide emissions from soil carbon loss and fossil fuel use, and nitrous oxide emissions from nitrogenous fertilizer application on farmland accounted for 60% of total GHG emissions (Chabbi et al. 2017; Chalise and Naranpanawa 2016). If not actively addressed, these emissions will probably rise by 60% as the population rises due to being highly dependent on agricultural production in terms of food needs (Henry 2020; Thornton et al. 2018).

Furthermore, limiting climate change impacts in SSA to 1.5 °C requires major changes to agriculture in this region,

Table 1 Search string used for the SLR

Database	Keywords used for searching
Scopus	((“agriculture*” impact*” OR “GHG*” OR “land-use*” OR “energy-use*”) AND (“strategy*” OR “measure*” OR “mitigate*”) AND (“crop*” OR “agriculture*” OR “livestock*” OR “farm*” climate*”) AND (“urban agriculture*” OR “sub-Sahara*”))
Web of Science	((“agriculture*” impact*” OR “GHG*” OR “land-use*” OR “energy-use*”) AND (“strategy*” OR “measure*” OR “mitigate*”) AND (“crop*” OR “agriculture*” OR “livestock*” OR “farm*” climate*”) AND (“urban agriculture*” OR “sub-Sahara*”))
Google Scholar	((“agriculture*” impact*” OR “GHG*” OR “land-use*” OR “energy-use*”) AND (“strategy*” OR “measure*” OR “mitigate*”) AND (“crop*” OR “agriculture*” OR “livestock*” OR “farm*” climate*”) AND (“urban agriculture*” OR “sub-Sahara*”))

from how we plant, to land and energy use as well as forests management (Davis-Reddy 2018). Implementing these changes could be a serious challenge for agriculture than for other sectors (Masson-Delmotte et al. 2021). However, understanding these variations is critical not just for understanding what various gas emissions might do in the context of mitigating climate change via agriculture, but also for informing policy decision-makers in SSA.

Agricultural land-use change and degradation in the context of climate change

Land-use change significantly contributes to climate change in SSA (Borrelli et al. 2020; Popp et al. 2017). Large-scale changes in land use like deforestation and soil erosion or machine-intensive farming methods contributed to increased contents of carbon concentrations in the atmosphere (Ngarava et al. 2023). Likewise, soil erosion through water, wind, and excessive tillage practice affects both agriculture as well as the natural environment (Robinson 2020). Soil loss, and its associated impacts, is one of the most important but least well-known environmental problems (Ebhota and Tabakov 2021). Generally, land degradation occurs from various land use, including forestry and agriculture, accounting for about 23% of all human GHG emissions (Robinson 2020).

GHGs have been part of humanity since agriculture was widely adopted and the associated population increase (Ngarava et al. 2023). There are indications that levels of GHGs in the atmosphere, particularly carbon dioxide (CO_2) and methane (CH_4), have already begun to rise over decades as a result of expanding agriculture, forest clearing, and animal domestication (Maindi et al. 2020). Land degradation is a serious driver of climate change through the emission of GHGs and the reduced rates of carbon uptake in soil (Tione et al. 2022).

Since the 1990s, the forest area in SSA has decreased by approximately 4% as a result of various agricultural land-use changes, resulting in net decreases in the tropics and net increases outside the tropics (Powlson et al. 2016). Furthermore, lower carbon density in re-growing forests compared to carbon stocks before deforestation results in net land-use change emissions (Ntinyari and Gweyi-Onyango 2021). Forest management that reduces forestland carbon stocks causes emissions, but overall estimates of these emissions are uncertain (Ntinyari and Gweyi-Onyango 2021). Out of all the land degradation processes in SSA (Appendix 5), deforestation as a result of indiscriminate felling of trees, increasing wildfires, degradation of organic soil, as well as biomass fire contributed majorly to climate change through the release of GHGs and the reduction in soil carbon sinks (Tione et al. 2022).

The processes of land degradation have substantial impact on CO_2 exchange with the atmosphere because of their direct influence on soil and terrestrial biota (Ackerl et al. 2023). The most common kind of land degradation, erosion, results in the loss of topsoil, which typically contains the highest concentrations of organic carbon, and hence increases mineralization and CO_2 release to the atmosphere (Chabbi et al. 2017; Outhwaite et al. 2022). Complementary processes like carbon burial may compensate for this impact, turning soil erosion into a long-term carbon sink (Adusah-Poku 2016). Conversion of primary land to unmanaged forests, illicit logging, and unsustainable forest management all resulted in GHG emissions and would have further effects on regional climate, including albedo changes (Kim et al. 2021). These interactions call for serious integrative climate impact assessments.

Agricultural energy use in the context of climate change

In SSA, agricultural energy use is an intriguer aspect of modern farming practices which contributes significantly to climate change (Ebhota and Tabakov 2021). It encompasses the energy consumed for various agricultural activities, including land preparation, irrigation, planting, fertilization, pest control, harvesting, processing, transportation, and distribution of agricultural products (Maino and Emrullahu 2022; Mirzabaev et al. 2023). Agricultural energy use is primarily dependent on fossil fuels, such as diesel for tractors and machinery as well as natural gas for irrigation, food processing, and other agricultural activities (Ngarava et al. 2023). Notably, the combustion of these fossil fuel release GHGs, particularly carbon dioxide (CO_2) and methane (CH_4), into the atmosphere which contribute to greenhouse effect which impacts climate change (Robinson 2020). The exact proportion varies depending on regional agricultural practices and the level of mechanization (Kim et al. 2021).

In many regions of SSA, especially semi-arid regions, agricultural practices rely heavily on irrigation to for crop propagation (Cockx et al. 2019). For instance, approximately 75% of food crop farmers in Southern Africa (countries like South Africa, Botswana, Malawi, Lesotho, Namibia, and Zimbabwe) relies heavily on irrigation as alternate source of water for their farms due to unpredictable rainfall and rising temperature (Davis-Reddy 2018). Therefore, the pumping and distributing water for irrigation can be energy-intensive, especially when using groundwater sources (Ackerl et al. 2023). The energy required for irrigation can lead to additional GHG emissions if it comes from fossil fuel-based sources (Ebhota and Tabakov 2021).

Likewise, the transportation of agricultural products and the processing of crops and livestock in Western African countries (such as Ghana, Senegal, Nigeria, and Togo) into various food products also consume energy, much of which comes from fossil fuels (Leitner et al. 2020). This adds to the carbon footprint associated with the agriculture-energy use in SSA (Ogunbode et al. 2020). According to Outhwaite et al. (2022) and Robinson (2020), understanding the impact of agricultural energy use on climate change is crucial for achieving sustainable agricultural practices and mitigating global warming. Addressing these consequences requires transitioning to more sustainable and climate-friendly farming practices. Encouraging the adoption of renewable energy sources, promoting efficient use of resources, implementing agroecological practices, and enhancing carbon sequestration in soils are some of the strategies that can help mitigate the negative impacts of agriculture-energy use on climate change.

Food crop production and climate change

The overall compositions of GHGs emitted through the food crop production in SSA does not reflect the overall emissions balance, notwithstanding, it contributed actively to generating around half of all methane emissions and about three-quarters of nitrous oxide emissions (Robinson 2020). In SSA, large emissions of methane and nitrous oxide (Appendix 6) occurred directly via crop cultivation, through urea and lime applications to farms as well as residue burning which also constitutes in CO_2 emissions but in small portions (Leitner et al. 2020). Nitrous oxide emissions mainly occur during the application of nitrogen-rich fertilizers to farmland (Sánchez-Rodríguez et al. 2018). It could also originate from manure application or the burning of fossil fuels in engines (Liu et al. 2019).

Likewise, carbon dioxide emission occurs through the burning of fossil fuels used in powering agriculture machinery for tillage (Abbass et al. 2022; Tongwane and Moeletsi 2018). However, these direct emissions via agriculture are comparatively enough to influence climate change coupled with other human-induced emissions (Ackerl et al. 2023). Energy use CO_2 either from agricultural operation practices (tractor fuels) or embedded agricultural inputs (fertilizer manufacture), could be included as a food system emission source, but are highly uncertain (Gopalakrishnan et al. 2019). The routes in emission reductions from all these sources are likely to be the overall decarbonization of energy generation sources, rather than specific agricultural mitigations (Boateng et al. 2019).

In addition, research (Legg 2021; Omotayo et al. 2022) reported that the food system of western and southern Africa is one of the major causes of GHG emissions through ongoing land-use change, primarily from clearing land for crop cultivation and pasture. Specifically, about 15% of annual emissions are attributed to net land-use related GHG emissions in five African countries: Niger, Uganda, Malawi, Cape Verde, and Zambia. Of this total, 10% can be traced back to crop cultivation, while the remaining 5% comes from pasture, crop residue burning, and deforestation (Chabbi et al. 2017; Outhwaite et al. 2022). The reports of (Praveen and Sharma 2019; Tongwane and Moeletsi 2018) on GHG emission in some selected nations of SSA showed that other GHGs apart from CO_2 emitted from food crop production have increased from the observed trend of 5.82 Gt.CO_2eq/yr in 2018 to projected emission of around 6.95 Gt.CO_2eq/yr by the year 2030. Given the central importance of food in our lives, crop production activities have increased and will continue to increase the concentration of anthropogenic GHGs emissions in SSA (Ackerl et al. 2023).

In addition to its contribution to various anthropogenic GHG emissions in SSA, agriculture is also responsible for varying negative impacts on the environment (Borrelli et al. 2020). Nitrogen-rich Fertilizers could pollute the water body as well as threaten the aquatic ecosystems through surface runoff. Likewise, pesticides, herbicides, and excessive tillage would lead to a loss of biodiversity (Outhwaite et al. 2022). As the population increases, agricultural production must expand and be more efficient and sustainable to meet the population surge (Chabbi et al. 2017; Outhwaite et al. 2022). Increasing land area for crop cultivation offers one option for increasing production but has its setback (Ackerl et al. 2023). Land preparation for farming purposes could destroy natural ecosystems, which would have a devastating impact on wildlife and biodiversity (Kim et al. 2021). Notwithstanding, constant exploitation of soils due to crop farming could lead to erosion as well as compaction, thereby leaving the land useless for future generations and in long run influencing climate change in the location (Borrelli et al. 2020).

Livestock production and climate change

Livestock production contributes both directly and indirectly to climate change through the emissions of GHGs such as carbon dioxide, methane, and nitrous oxide (Maindi et al. 2020). In SSA, this sector contributes around 18% (7.1 billion tonnes CO_2 equivalent) of GHG emissions (Graham et al. 2022). It also generated more than 3 billion tonnes of CO_2eq/yr while post-farm transport and processing account for only a few fractions of the GHG emissions, linked to livestock production (Ackerl et al. 2023). GHG emissions (Appendix 7) through livestock production are generated from either the digestive system of livestock through the production of a by-product called enteric fermentation or from livestock dungs which contains organic compounds such as methane and nitrous oxide (Chabbi et al. 2017).

In a collaboration effort investigating GHG emissions across the livestock value chain in selected regions of SSA, researchers (Petersen et al. 2023; Robinson 2020) found that enteric fermentation is the primary contributor to GHG emissions, along with feeding, animal dung, and energy consumption. Additionally, Henry (2020) and Mirzabaev et al.

(2023) stated that the generation of methane is a significant problem in cattle production in SSA since it accounts for about 18% of the total GHG emissions (Robinson 2020). In addition to environmental and climate goals, the agricultural sector should include biodiversity, nutritional needs, food security, rural farmers' livelihoods, and rural communities as important issues (Graham et al. 2022). Agriculture has addressed humanity's greatest challenges throughout its history (Davis-Reddy 2018). This sector has raised food production to levels that many thoughts were unattainable (Borrelli et al. 2020). The sector now faced the task to make another significant contribution to humanity's progress by lowering GHG emissions. It is conceivable and desirable to create management techniques to reduce methane emissions from ruminant and non-ruminant livestock to adjust to total GHG contributions to climate change.

Urban agriculture and climate change

Over the last few decades, urbanization has spread fast and steadily around the globe (Ogunbode et al. 2020). More than half of the world's population lives in cities, and this ratio is expected to climb to almost 70% by 2050 (Pradhan et al. 2023). Cities use up to 80% of the energy generated globally and contribute for more than 70% of energy-related global GHG emission, with both statistics predicted to rise (Esmail and Oelbermann 2022). It is anticipated that emerging nations, particularly fast-growing cities in SSA, would account for about 60% of the increase in CO_2 emissions from agriculture and energy usage by year 2050 (Robinson 2020). Additionally, inadequate waste management and agricultural debris in many cities leads to nitrous oxide and methane emissions (Hanif 2018).

As a result of the population surge that comes with urbanization, urban agriculture plays a viable solution to meet the high demand for food in the cities (Pradhan et al. 2023). According to (Esmail and Oelbermann 2022; Pradhan et al. 2023), urban agriculture is the practice of cultivating land inside city or suburb, community gardens, rooftop farms, hydroponic, aeroponic, and aquaponic facilities, as well as vertical production, for agricultural purposes (Thornton et al. 2018). This urban land use pattern can also pose problems for the environment and climate change if not well managed (Pradhan et al. 2023). Due to networking commerce and increased globalization, food now travels great distances from farm before reaching their plates (Robinson 2020). This has prompted worries about GHG emission from the transportation sector in relation to food value chain in urban areas (Hanif 2018).

Furthermore, Crippa et al. (2021) and Hanif (2018) reported that the negative environmental impacts of GHGs on climate are also brought on by the subsequent stages in urban agricultural food production such as propagation, processing, consumption, disposal, digestion, and water reuse. This constitutes about 50% of the overall GHG emissions attributed to the food industry in SSA (Tongwane and Moeletsi 2018). In addition, the increased usage of land for agriculture to meet urban food needs has had far-reaching consequences (Davis-Reddy 2018). When these factors are taken into consideration, it is estimated that food production in the form of home garden, and community farms are responsible for about 30% of the SSA cities' total carbon footprint (Ebhota and Tabakov 2021).

As Pradhan et al. (2023) and Praveen and Sharma (2019) noted urban community farms serve to lessen the biodiversity loss that comes with industrial farming. It has also been brought to light that community farms can lessen our environmental impact by diverting trash from landfills via agricultural practices such as usage of little packaging, onsite recycling of commonly used appliances, and composting of organic scraps (Cockx et al. 2019; Kumar et al. 2021). This kind of urban land use is growing in popularity, and it may affect GHG emissions through the use of fertilizers, herbicides, and agrochemicals unsustainably (Ngarava et al. 2023). There is currently limited quantitative evidence on the associated contribution of urban agriculture projects like community farms, despite (Abernethy and Jackson 2022; Esmail and Oelbermann 2022) proposal that local production of fruit and vegetables reduced GHG emissions associated with food transport, distribution, and retail. According to Abbass et al. (2022) and Scott et al. (2023), laws are being passed, advisory organizations like the Rural and Urban Climate Change Forum are being funded, and road maps for more sustainable supply chains are being developed as part of government strategy to reduce greenhouse gas emissions associated to food production in urban regions.

Various greenhouse gas sink: impact on climate change

Climate change has a significant impact on human habitat as well as livelihood conditions; likewise, our ways of life had a significant influence on climate change (Henry 2020). As changes increase larger and faster, there is a chance that adverse outcomes may continue to dominate. GHG emissions in SSA have grown due to increased population, rapid industrialization, and intensive agriculture practices (Robinson 2020). The use of fossil energy, deforestation, biomass burning and decay, as well as land degradation have all contributed to rising atmospheric CO_2 concentrations, which are now at (0.04%) 421 ppm and expected to rise to around 500–600 ppm by 2050 (Appendix 8) (Liu et al. 2019).

Following Abbass et al. (2022) and Tongwane and Moeletsi (2018), different sectors contributed significantly to GHG emissions in SSA. The energy sector contributes the most, closely followed by industrial, deforestation (through tree felling, burning, and hacking) as well as intensive agricultural practices, and transportation. The waste from commercial and residential buildings is the least polluting sector (Legg 2021; Masson-Delmotte et al. 2021). All of these sectors contribute to the overall anthropogenic activities that lead to climate change.

Methane (CH_4) emissions

In 2020, methane accounted for around 15% of all GHG emissions from human activities in SSA (Robinson 2020). The various human activities emitting methane are leaks from natural gas systems, the raising of livestock, and natural wetlands (Robinson 2020). In addition, about 65% of overall CH_4 emissions also come from energy, industry, agriculture, land use, and waste management activities, as described below (Robinson 2020).

Agriculture: Domestic livestock (such as cattle, swine, sheep, and goats) generate CH_4 naturally as part of their digestive process (Robinson 2020). Since these animals are raised by human for food and other purposes, their emissions are deemed human-related (Smith et al. 2016). The agriculture sector is the leading source of CH_4 emissions in the SSA, although emissions can also occur as a result of land conservation and management activities as well as forestry management (through forest and grassland fires, organic matter decomposition in coastal wetlands) (Chalise and Naranpanawa 2016).

Energy and Industry: Natural gas and petroleum systems are also significant contributors to CH4 emissions in SSA (Davis-Reddy 2018). Methane is released into the atmosphere via natural fossil fuel extraction, as well as crude oil production, refining, transportation, and storage. Coal mining also contributes to CH4 emissions (Legg 2021).

Waste from Homes and Businesses: Methane gas is generated from landfills when garbage decomposes, during home and industrial wastewater treatment as well as during composting and anaerobic digestion (Boateng et al. 2019). Methane is also emitted by a variety of natural sources, including wetlands, which produce CH_4 from microorganisms that decompose organic compounds in the absence of oxygen. Termites, seas, sediments, volcanoes, and wildfires are examples of smaller methane emission sources (Borrelli et al. 2020; Popp et al. 2017).

Carbon dioxide (CO_2) emission

The primary GHGs emitted by human activities is carbon dioxide (CO_2) (Bakshi et al. 2019; Ogunbode et al. 2020). CO_2 accounts for almost 80% of total SSA greenhouse gas emissions from human-related activities in the year 2020 (Boateng et al. 2019). According to Ngarava et al. (2023), CO_2 is found naturally in the atmosphere as part of the Earth's carbon cycle (the natural circulation of carbon among the atmosphere, oceans, soil, plants, and animals). Human-related activities are influencing the carbon cycle, both by releasing more CO_2 into the atmosphere and by altering natural sinks' ability (such as forests and soils) to take and store CO_2 from the atmosphere (Davis-Reddy 2018). While CO_2 emissions come from varieties of natural sources, human-related emissions are responsible for the rise in atmospheric CO_2 during the industrial revolution, which has a relatively large impact on the climate (Robinson 2020). Aside from agriculture and land use, burning fossil fuels for energy use and transportation purposes are part of human activities that generate CO_2 in SSA (Crippa et al. 2021). CO_2 is also emitted by some industrial activities (Tione et al. 2022). The following sections detail the major sources of CO2 emissions in the SSA.

Transportation: In the 1990s, the combustion of fossil energy such as gasoline and diesel to transport people and goods was the major source of CO_2 emissions, accounting for around 16% of total CO_2 emissions and 22% of total greenhouse gas emissions in SSA (Scott et al. 2023). This includes domestic transportation sources like highway and passenger vehicles, air travel, marine transportation, and rail (Kanitkar et al. 2022).

Electricity: Electricity is a significant energy source in the SSA, used in powering homes, businesses, and industries (Adams and Acheampong 2019). The combustion of fossil fuels to generate electricity constitutes the major source of CO_2 emissions in SSA, thereby accounting for around 16% of total CO_2 emissions (Adams and Acheampong 2019). The kind of fossil fuels used in generating electricity emit different amounts of CO_2 (Henry 2020). Therefore, by producing a certain quantity of electricity, the burning of coals will produce more CO_2 than natural gas or oil (Ackerl et al. 2023).

Industry: Numerous industrial processes emit CO_2 through fossil fuel combustions as well as through chemical reactions such as the production of mineral products, cement, and metals (like iron and steel) that do not involve combustion (Liu et al. 2019). In addition, many industrial processes also make use of electricity for energy generation; therefore, indirectly complement CO_2 emissions through the industrial source (Adams and Acheampong 2019).

Nitrous oxide (N_2O) emissions

Nitrous oxide (N_2O) accounted for around 17% of all SSA GHG emissions through human-related activities (Abbass et al. 2022). Human-related activities like agriculture, industrialization, energy use, and wastewater management increase the amount of N_2O in the atmosphere (Ogunbode et al. 2020). N_2O is also present naturally in the atmosphere being part of the Earth's nitrogen cycle and has a variety of natural sources (Chabbi et al. 2017; Outhwaite et al. 2022). N_2O is emitted from other various sources such as agriculture, land use, transportation, and industry, as described below (Scott et al. 2023).

Agriculture: Various agriculture soil management activities in SSA like the application of synthetic or organic fertilizers and other cropping practices, the management of manure, or the burning of agricultural residues generate N_2O (Borrelli et al. 2020; Popp et al. 2017). Agriculture soil management is the largest source of N_2O emissions in the SSA, accounting for about 64% of total N_2O emissions in 2020, closely followed by the application of synthetic nitrogen fertilizers to urban soils (lawns, golf courses) and forest lands (Adams and Acheampong 2019).

Fuel Combustion: N_2O is also emitted through the combustion of fuels (Gopalakrishnan et al. 2019). The amount of N_2O emitted to the atmosphere from fuel combustions depends on the type of fuel combusted, combustion technology, maintenance, as well as operating practices (Robinson 2020).

Industry: N_2O is generated as a by-product during the production of chemicals like nitric and adipic acid which is used in making synthetic commercial fertilizers, nylon, and other synthetic products (Robinson 2020).

Waste: It is also generated during nitrification, which involves the treatment of domestic wastewater as well as the denitrification process of nitrogen present urea, ammonia, and proteins (Leitner et al. 2020).

Stylized facts on agriculture-energy use as a true contributor to climate change

Climate change is reported to have been triggered by anthropogenic human-related activities through GHG emissions, which have drastically affected the nitrogen and carbon cycles, enhancing the risks of pollution and global warming (Boateng et al. 2019). GHG emissions are expected to increase due to existing land-use alterations practiced in SSA regions (Ackerl et al. 2023). Although the fluxes are anticipated to be substantial, there are numerous uncertainties in the estimations reported due to the limited temporal and spatial representation of agricultural soil emissions (Ackerl et al. 2023).

Land changes and agricultural energy use have a significant influence on carbon sequestration and GHG emissions in SSA (Mullins et al. 2018). Plants absorb CO_2 from the atmosphere, plants, forests, and many other natural ecosystems that have evolved over thousands of years could store enormous amounts of carbon (Outhwaite et al. 2022). The transformation of uncultivated land from a carbon sink and store to a source of GHG emissions owing to burning plant material or crop cultivation has a detrimental influence on the emission balance and climate (Tione et al. 2022). Similarly, maintaining and expanding plant biomass aids in the sequestration of carbon and reduces the concentrations of atmospheric CO_2, CH_4, and N_2O (Tongwane and Moeletsi 2018).

According to Abbass et al. (2022) and Tongwane and Moeletsi (2018), the main driver of climate change in Ethiopia, Sudan, Chad, and Niger is deforestation (for agricultural expansion and fuel wood). Similarly, intense tillage is a traditional land-use technique in Mali, Guinea, and Mauritania that contributes significantly to climate change by continually disrupting the topsoil (Tongwane and Moeletsi 2018). These practices increase CO_2 and CH_4 emissions by inducing soil organic matter decomposition and soil erosion (Ngarava et al. 2023). As a result, forestry and woodland management have also influenced the concentration of GHGs in the atmosphere, resulting in climate change (Robinson 2020).

Various research (Gopalakrishnan et al. 2019; Omotayo et al. 2022; Pradhan et al. 2023) have found that unsustainable contemporary agricultural practices in some SSA regions constitute a substantial source of GHGs that exacerbate climate change. Agriculture practice varies across SSA, resulting in a diverse range of agricultural contributions to climate change (Omotoso et al. 2023). GHG emissions from agriculture are severe in Eastern African nations (such as Kenya, Ethiopia, Uganda, and Djibouti) due to large numbers of cattle and inadequate waste management, inefficient use of agrochemicals, and mismanagement of farmland (Robinson 2020). Furthermore, energy use in agriculture, such as a tractor for land clearing, fertilizer application machinery, and tillage practices in some Southern African nations like Zambia, Zimbabwe, Namibia, and Botswana, significantly altered the nitrogen and carbon cycles, contributing to GHG emissions and climate change (Davis-Reddy 2018).

In addition, organic farming in Western Africa (such as Nigeria, Ghana, Togo, Burkina Faso, and Senegal) contributes significantly to GHG emissions due to a lack of crop residue management since most agricultural wastes in these countries are publicly burnt or left for animal grazing (Ngarava et al. 2023). Likewise, savanna or grassland fires, which seem to be prevalent in the region, are a significant contributor to GHG emissions (Legg 2021; Masson-Delmotte et al. 2021). Because of the large contribution of GHG emissions to ecosystems, agriculture has emerged as an integral sector that SSA and the entire world should focus on to manage emissions and preserve current and future generations from devastating climate change (Robinson 2020).

Economic impacts of climate change in various sub-Saharan Africa nations

The SSA is one of the world's poorest regions, with an estimated 421 million people living on less than $1.20 a day (Robinson 2020). They are recognized as the most susceptible to climate change because they have the fewest financial and technological means to deal with its impact (Omotoso et al. 2023). Climate-related disasters, particularly droughts and floods, are the most prevalent types of natural disasters in SSA (Omotoso et al. 2023). As a result, they account for around 80% of the casualties and around 70% of the economic losses as a result of natural disasters in SSA (Omotoso et al. 2023). Flooding and droughts are projected to become more frequent and intense in the future, due to poor institutional structure, weak infrastructure, and adaptive measures (Chalise and Naranpanawa 2016; Davis-Reddy 2018).

Climate change is expected to influence agricultural activity in SSA (Appendix 9) by shortening the growing season, increasing water stress, and raising the prevalence of disease, insect, and weed outbreaks (Robinson 2020). Heat and water stresses are regarded as the most severe environmental factors resulting from climate change that affect agricultural production systems (McCarthy et al. 2022; Robinson 2020). However, in regions with excessive water and heat (due to climate change), disease, weed, and insect infestations are expected to wreak further havoc on agroecosystems (Maino and Emrullahu 2022). Moreover, the carbon-cycle distortions are anticipated to have an impact on livestock and food crop production such as wheat, rice, soybean, maize, sugar cane, millet, and sorghum (Robinson 2020).

Furthermore, climate-related shocks are predominantly hitting SSA, a subcontinent that contributes 2% of global GDP in 2021, is home to about 15% of the present world's population and will account for more than half of the anticipated global population by 2100 (Abbass et al. 2022). This is largely due to the region's geographic vulnerability, low income, increased reliance on climate-sensitive industries, and inadequate ability to adapt to weather shocks (Ngarava et al. 2023). Droughts in the Sahel, for example, would have an impact on economic growth and, in particular, agricultural productivity (Ngarava et al. 2023). Droughts and flooding can result in a huge number of casualties (Robinson 2020). For example, the 2018–2019 rainy season in SSA inflicted unprecedented amounts of disaster, displacing about 2.2 million households in Malawi, Mozambique, and Zimbabwe (Kim et al. 2021; Mirzabaev et al. 2023).

Mozambique's economic losses have resulted in a slowing of GDP growth to 2.5% in 2019, as opposed to the anticipated rise of up to 4.7% (Kim et al. 2021). Because of the sensitivity of their key engines of growth, such as agriculture, forestry, pastoralism, energy, tourism, and water resources, empirical findings show that African economies are very vulnerable to changes in climatic variables and climate-related events (Borrelli et al. 2020).

Numerous researchers (Abernethy and Jackson 2022; Bakshi et al. 2019; Davis-Reddy 2018; Petersen et al. 2023) investigated the impacts of rising temperatures on economic growth in SSA from 2000 to 2019, utilizing panel data from 26 SSA nations. They discovered that a 1.0 °C increase in temperature in a given year reduces economic development by 1.3% points on average in poorer nations, whereas the impact is minimal in wealthier countries. Their findings indicated that higher temperatures have a big impact on poorer regions since they rely excessively on climate-sensitive industries (such as agriculture and forestry) and have few resources (low income and savings) to adapt to weather shock (Omotayo et al. 2022).

In addition, Abbass et al. (2022); Henry (2020); and Thornton et al. (2018) evidence that prolonged changes in climatic conditions (like variations in precipitation, temperature, and sunlight) had a long-term negative impact on economic growth per capita in SSA countries. Also, Boateng et al. (2019) and Tione et al. (2022) discovered that following a natural disaster, difficulties in economic growth are exacerbated by bigger current account deficits, mounting fiscal and debt vulnerabilities, and pressures on international reserves. Remittances, foreign aid, and reconstruction can assist in minimizing the negative growth implications in the short term (Maino and Emrullahu 2022). Renovations of damaged infrastructure can assist in minimizing physical capital losses (Thornton et al. 2018). Human capital loss from disaster-related mortality, starvation, or decreased school attendance, on the other hand, is irreversible (Bakshi et al. 2019).

Climate change adaptation practices and agriculture in sub-Saharan Africa

It is crucial to reduce agricultural GHG emissions and that of the net food system. CO_2 emissions must be abolished, and lowering agricultural CH_4 and N_2O emissions is climatically beneficial and should be advocated (Robinson 2020). Climate change adaptation is a continuous activity that necessitates site-specific responses (McCarthy et al. 2022). Adaptation strategies should end up making agricultural systems more sustainable by adopting contemporary farming technologies that minimize GHG emissions (Robinson 2020). Differentiated adaptation approaches and enhanced climate-risk management assistance for agricultural and farming households are crucial ways to cushion the impact on climate (McCarthy et al. 2022).

These adaptation strategies involve, in particular, the choice and substitution of species and varieties, the adaptation of fieldwork to seasonal changes, the modification of plant production practices (efficient fertilization and irrigation practices), along with the adoption of plant production techniques that preserve soil organic matter content, manure management, and agroforestry practices (McCarthy et al. 2022).

Key roles of adaptation practices on agriculture and energy use impacts

The impacts of agriculture on climate change can be sustained through climate change adaptation processes which involve the recognition of carbon (C) as a tradable commodity and the reduction in GHG emissions for agriculture and its energy use (Chalise and Naranpanawa 2016). These processes entail focusing on ways of adjusting to emissions of GHGs (Appendix 10) from the agriculture sector by employing natural resource conservation measures without compromising food production in terms of meeting the growing population's demands (Boateng et al. 2019). This will be a triple win given that it will enhance adaptation while also increasing food security and sustainability in the country (Abernethy and Jackson 2022; Ackerl et al. 2023).

The forestry sector which is the ideal conservation measure holds the key to successful adaptation techniques by trapping carbon through various forest management such as deforestation, degradation, afforestation, and reforestation (Ackerl et al. 2023). Other ways of GHG emissions adaptation in agriculture include enhanced crop and pasture land management (e.g., improved agronomic methods, fertilizer usage, tillage, and residue management), increased input usage efficiency, organic manure restoration of degraded lands, improved livestock and manure management, and agroforestry (Ngarava et al. 2023). In addition, GHG emission intensity from consumption would be reduced through the adoption of a diet that is plant based (Davis-Reddy 2018). Numerous scholars (Chabbi et al. 2017; Omotoso et al. 2023; Outhwaite et al. 2022; Robinson 2020) pinpointed that agricultural emissions eliminated in some selected states of SSA are achieved through more efficient agricultural techniques, such as smarter livestock handling, zero/minimal tillage, crop rotations, agroforestry, monitoring fertilizer application using technology and making adjustments to farm configuration during propagation.

Interestingly, imposing a carbon fee on agricultural operations would enhance the adaptation process which will result in the reduction of GHG-intensive agricultural commodities (Chalise and Naranpanawa 2016; Mirzabaev et al. 2023). Researchers (Omotoso et al. 2023; Robinson 2020) positioned that meeting the food need of SSA given the increasing populations while simultaneously adapting to GHG emissions requires drastic changes in production structure and energy use intensification. This could be done through a carbon offset program organized by the government for measuring carbon emitted during agricultural production as well as drastically enhancing energy efficiency in the food production process (Maino and Emrullahu 2022). These initiatives will greatly decrease GHG emissions from agricultural and energy usage, significantly lowering the rate of climate change, improving environmental sustainability, reducing pollution, and better human health (Robinson 2020).

Land use for climatic advantages, like sequestering carbon or biomass for energy, is emphasized as vital for ambitious adaptation approaches (Kanitkar et al. 2022). Acknowledging that agricultural land is used for more than just these uses, but primarily for food production, will go a long way toward assisting adaptation efforts (Chalise and Naranpanawa 2016). Measures to reduce agricultural emissions may thus be connected to initiatives to sequester carbon through land use (Robinson 2020). Greater emphasis must be placed on alternate land use and energy use in agriculture since agricultural emission adaption solutions could either support or interfere with other Sustainable Development Goals in SSA (Crippa et al. 2021).

Climate change adaptation practices in some selected countries of the sub-Saharan Africa

A significant issue in SSA is farmers' improper management of soil nutrients and land use (Tione et al. 2022). Most farmers do not know how to use resources effectively to cut back on GHG emissions that contribute to climate change (Robinson 2020). Enhancing nutrient usage efficiency offers a significant chance of lowering indirect carbon dioxide emissions from fertilizer businesses as well as N2O emissions from crops, which are normally produced by soil microorganisms from nitrogen surpluses (Leitner et al. 2020). According to Leitner et al. (2020) and Sánchez-Rodríguez et al. (2018), some recommended farming techniques include using the proper resource (higher-efficiency fertilizer) at the proper rate, time, and location.

Improved nutrient management is seen as a more effective and realistic option (Appendix 11) for overcoming the challenges connected with GHG emissions' implications on climate change in SSA (Omotoso et al. 2023). Adopting enhanced agronomic techniques can result in higher yields and the creation of more carbon, which can be utilized to increase soil carbon storage, resulting in fewer losses to the environment (Ebhota and Tabakov 2021; Robinson 2020). Other strategies proposed include lengthening crop rotations, utilizing better cultivars, and employing mixed cropping with perennial crops, which will result in higher underground carbon storage.

Climate change adaptation practices: a Panacea to the greenhouse gas emissions

Agriculture, forestry, and other land use accounted for major anthropogenic GHG emissions in SSA, mostly from non-CO_2 GHGs (CH_4 and N_2O) and indirect CO_2 emissions from induced deforestation (Outhwaite et al. 2022). Reducing these emissions is key to achieving net-zero objectives of GHG adaptation IPCC (Emenekwe et al. 2022; Kanitkar et al. 2022). Also, Bahri et al. (2021) and Ngarava et al. (2023) estimate that the adaptation potential for agriculture (excluding forestry and fossil fuel offsets from biomass) will be between 10.5 and 16.0 $GtCO_2$-eq/yr by 2030, where around 89% are assumed to be from carbon sequestration in soils. Therefore, the assessment of adaptation potential and prospects remains a major tool for priority setting at the national and regional levels in SSA (Ogunbode et al. 2020; Robinson 2020).

Many of these agriculture-enhanced options particularly those that involve soil carbon (C) sequestration also increased adaptation potentials, food security, and economic development (Borrelli et al. 2020; Popp et al. 2017). These strategies entail enhancing soil organic matter levels and reducing GHG emissions from agriculture, land use, and energy use (Boateng et al. 2019). However, some of these options in the long run resulted in poor trade-offs, with mitigation advantages but severe effects on food security and economic development (Malla et al. 2022). Biofuel production, for example, provides a clean substitute for fossil fuels but may displace or compete for water and land resources required for food production (Davis-Reddy 2018; Kim et al. 2021).

Planting of cover crops which might also be useful in biofuel production, helps in organic soil restoration but it may lower the amount of land suitable for food production (Kim et al. 2021). Rangeland restoration may boost carbon sequestration but also reduce herder income in the near term by decreasing the number of cattle. Some trade-offs can be regulated by efficiency measures or through the offering of incentives/compensation which may be beneficial for agricultural development but not adaptation strategies (Robinson 2020). However, complementing climate-smart agricultural practices with climate-friendly policy implementation (such as afforestation, agroforestry, and use of solar energy to fossil fuel) can limit the impact of climate change to 1.5 °C from GHG emission (Ogunbode et al. 2020). In reality, would lead to substantial impacts on food availability, cleaner air, and overall economic development of a nation (Mirzabaev et al. 2023).

Conclusion and policy recommendation

Management of land and energy use in agriculture has a significant impact on GHG concentrations in the atmosphere. Apart from CO_2 emissions via combustion of agriculture and animal waste combustion in SSA reported in literatures, livestock production significantly contributes to CH_4 emissions. Meeting the food demand of the world's growing population while combating climate change is a difficult task that cannot be accomplished overnight. Similarly, achieving a 1.5 °C pathway (as recommended by IPCC) will necessitate an industry-wide effort and collaboration of consumers, farmers, investors, and regulators to significant shifts in how we farm. Without swift action, emissions of GHGs in agriculture, land, and energy use will continue to rise and lead to the overheating of the ozone layer. Understanding GHG emissions by sources and removal by sinks in agriculture is essential for devising effective GHG reduction and adaptation strategies. The international bodies and stakeholders involved in climate change have urged the agricultural communities to limit GHG emissions to safeguard the environment while still meeting the demands of a growing population and food supply. This complicated issue necessitates a coordinated and consistent policy approach to climate change, agricultural growth, and energy use. In the face of climate change and competition for scarce resources, the entire food system will have to reform and become more resource efficient, while also consistently reducing its environmental impacts, including GHG emissions. We must boost yields while having little or no influence on climate change by minimizing our agrochemicals, eliminating food waste, and reducing our consumption of greenhouse gas-intensive foods through adequate investments from governments and all stakeholders in SSA. Therefore, policies and incentives that promote sustainable land use such as agroforestry and conservation tillage and energy-efficient practices in agriculture including carbon pricing and subsidies for green technologies should be implemented. Enhanced research and innovation in sustainable agriculture and renewable energy to develop more efficient and climate-friendly solutions is necessary.

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Declarations

Conflict of interest The authors declare no competing interests.

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