



Insights on agricultural greenhouse gas research and collaboration in Southern Africa

Pamela Pophiwa¹ · Ackim Mwape² · Abubeker Hassen³ · Cornelius J. L. du Toit³ · Este van Marle-Koster³ · Lindiwe M. Sibanda³

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Abstract

Food security and climate change challenges in Southern Africa have prompted research initiatives for agricultural productivity, adapting to climate change, and reducing greenhouse gas (GHG) emissions. Still, the scale, scope, and complexity of the problem have not been addressed. One notable challenge is the lack of interconnections, information flows, and knowledge exchange among research programmes. Better coordination of actors involved in climate-smart agricultural research is needed to utilise resources more effectively and avoid duplication of work. The paper presents the results of a scoping literature review and the assessment of existing research programmes on agricultural GHG emissions in nine Southern African countries. Feedback from stakeholders was obtained through a survey and stakeholder workshops. The results show that agricultural GHG research is gaining prominence. The main research themes included different aspects of livestock emission (53%), while the remainder covered soils, crops, and pastures. There is still a big research gap, with less than 40% of the papers originating from outside South Africa. Substantial work has been conducted, but the research is highly fragmented, and there is no large-scale regional institutional collaboration. Several researchers and institutions are engaged in research, but a lack of funding and infrastructure limits the capacity to generate scientific evidence. The outcomes of this study highlight the need for a regional programme that will facilitate research collaboration toward low-emission and climate-resilient food systems.

Keywords Food systems · Greenhouse gases · Climate change · Collaboration · Southern Africa · Policy

Introduction

Agriculture is an important socio-economic sector in the Southern African Development Community (SADC) region, contributing between 4 and 27% of GDP and accounting for approximately 13% of overall export earnings (SADC

2015). Furthermore, about 70% of the region's population depends on agriculture for food, income, and employment highlighting the importance of agriculture in regional food systems (SADC 2015). Despite its importance, the agriculture sector is highly vulnerable to the impacts of climate change and faces numerous climate-related risks. According to the Intergovernmental Panel on Climate Change (IPCC) report on climate impacts, adaptation, and vulnerability, the

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✉ Pamela Pophiwa
ppophiwa@gmail.com

Ackim Mwape
Ackim.Mwape@nzagrc.org.nz

Abubeker Hassen
abubeker.hassen@up.ac.za

Cornelius J. L. du Toit
Linde.dutoit@up.ac.za

Este van Marle-Koster
este.vanmarle-koster@up.ac.za

Lindiwe M. Sibanda
Lindiwe.sibanda@up.ac.za

- ¹ ARUA Centre of Excellence in Sustainable Food Systems, University of Pretoria, Pretoria, South Africa
- ² The Global Research Alliance on Agricultural Greenhouse Gases, Palmerston North, New Zealand
- ³ Department of Animal Science, Faculty of Natural & Agricultural Science, University of Pretoria, Pretoria, South Africa

region has been experiencing a warming trend over the past few decades and is projected to become warmer and drier as the level of global warming intensifies, making it a climate hotspot (IPCC 2022). Rising temperatures, changes in rain patterns, increased evaporation rates, and spatial shifts in optimum growing regions due to climate change have direct impacts on crop and livestock production (Davis-Reddy and Vincent 2017). Additionally, the predicted rise in average temperatures and erratic rainfall patterns in the region will add to extreme weather events such as droughts, floods, storms, heat waves, and wildfires already experienced in the region (IPCC 2022). These extreme weather events have a direct impact on agricultural productivity. The emergence of such climate risks necessitates urgent action to ensure resilient food systems through adaptation to climate change impacts and mitigation of greenhouse gas (GHG) emissions.

Currently, there are numerous research initiatives across the research ecosystem focused on enhancing agricultural productivity, adapting to climate change impacts, and reducing GHG emissions (Thornton et al. 2018). However, despite these efforts, their common impact has fallen short of addressing the scale, scope, and complexity of the challenges. According to IPCC (2017), reliable estimates of GHG emissions, particularly carbon flux, are scarce for Africa due to incomplete, fragmented, and inconsistent data on the continent's carbon budget.

The research ecosystem in Southern Africa is highly heterogeneous. Yet, there is a significant lack of representative, systematic, and harmonised research initiatives across the region. This fragmentation hampers the ability to assess and track agricultural GHG emissions effectively and to develop robust mitigation strategies (Grieco et al. 2019). Improved collaboration among actors is a critical first step toward sustainable development and guiding essential research investments (Chevallier 2023). The need for improved research coordination in Southern Africa has been apparent for many years. Future directions of research should include creating a comprehensive database of in situ studies as part of a collaborative framework aimed at improving the availability of low-cost GHG data (Grieco et al. 2019). Such frameworks, which are being promoted worldwide, help harmonise data collection methods and enhance the consistency and reliability of the collected data (Chevallier 2023).

Given the critical role that agriculture must play in meeting the objectives of the Paris Agreement (Nhamo 2018; Chevallier et al. 2021), there is an urgent need for ambitious policy action to accelerate emissions reductions and strive for net-zero emissions by 2050. Under current policies, SADC countries are unlikely to reduce emissions sufficiently to meet their Nationally Determined Contributions (NDC) targets for 2030 (Leahy et al. 2020; Arndt et al. 2022; Lamb et al. 2022). Significant knowledge gaps persist in agricultural GHG emissions research and

mitigation pathways, despite numerous initiatives aimed at promoting climate-smart agriculture (Grieco et al. 2019). There is insufficient engagement with stakeholders, including policymakers, industry actors, and farmer organisations, which hinders the translation of research findings into practical solutions (Chevallier 2023). Furthermore, current research efforts are often siloed and there are limited collaborative efforts in the region or commonly agreed-upon models that connect inputs, research activities, outputs, and outcomes to sustainability goals.

Another critical challenge is the limited research infrastructure and inadequate funding, which constrain the capacity of researchers to conduct high-quality studies. Many institutions lack the necessary equipment and resources, forcing researchers to rely on expensive external services. To address these challenges, climate-smart agricultural research across the SADC region would benefit from greater collaboration among all relevant stakeholders, including research institutions, academia, policymakers, supporting industries, the private sector, farmer organisations, funding organisations, and international agencies (Chevallier 2023). Improved collaboration through a strategic regional initiative could foster more rapid technological advancements, enhance the reliability of work, ensure consistent application of best practices (at the right cost and appropriate to local circumstances), and ultimately promote climate-resilient food systems. Specific to agricultural GHG research, cross-disciplinary and cross-institutional collaboration can (i) promote the sharing and collation of data and information (Radeny et al. 2020), (ii) help identify and compare the impacts of various agricultural GHG mitigation options, recommending best practices for policymakers, farmers, and other stakeholders (Negra et al. 2020), (iii) enable the pooling of resources and the sharing of national research infrastructures such as laboratories, observatories, databases, and repositories (Pinkse and Kolk 2012), (iv) promote the co-development and sharing of methods for quantifying GHG emissions (Negra et al. 2020), and (v) foster networking and knowledge exchange among researchers (Okner 2015). However, fostering effective collaboration is challenging, requiring significant time to build relationships and identify suitable partners and topics (Nelson and Dodd 2017). Effective collaboration also requires robust implementation mechanisms for the joint provision of outputs and outcomes and carries substantial fiscal implications.

This paper presents the results of a scoping literature review and assessment of existing research programmes on agricultural GHG emissions in Southern Africa. The study aims to understand the landscape of agricultural GHG research in the region, identifying areas of strength, potential gaps, and opportunities for collaboration and enhancement. The research questions driving the study are:

1. What are the current thematic focus areas and gaps in agricultural GHG research in Southern Africa?
2. What are the existing research capacities and infrastructure, and what limitations hinder effective agricultural GHG research?
3. How can collaborative research frameworks be structured to promote innovation and knowledge exchange in agricultural GHG research in the region?

Materials and methods

The study focuses on nine Southern African countries: South Africa, Botswana, Namibia, Zimbabwe, Zambia, Mozambique, Malawi, Lesotho, and Eswatini. The region is a climate hotspot that experiences climate-related challenges such as erratic rainfall and droughts, which impact agricultural productivity (IPCC 2022).

A combination of data collection methods was used. These include a scoping literature review, a structured survey of key researchers, and stakeholder consultations. This triangulated methodology was deemed appropriate to provide a robust assessment of the research landscape and evidence-based recommendations for promoting regional collaboration.

Scoping review of literature

A scoping review of peer-reviewed literature was conducted to identify key researchers in the field, collaborative networks, and research themes. This approach helps to understand the current state of research and collaboration within the field and to set a research agenda (Tricco et al. 2016).

The first step involved selecting relevant articles for analysis. Keywords were identified based on those used in previous studies (Chen et al. 2023) and expert recommendations in the field. The keywords used in this scoping review are listed in Table S1. A Boolean search approach was used to search the Web of Science bibliographic database. This search strategy involved (a) combining all search terms under each category listed in Table S1 using the 'OR' operator and (b) combining search items from each group with those from other categories using the 'AND' operator. This dual search strategy was previously used by Sweileh (2020) and it captures a wide range of relevant literature while maintaining focus on the specific research areas of interest. By using the 'OR' operator within each category, it broadens the search to include a variety of related terms, ensuring that all possible variations are captured. Combining the results from each category using the 'AND' operator, the search is narrowed to only those articles that address the intersection of the specified topics.

The Web of Science Core Collection served as the data source due to its broad coverage, high-quality content, and multidisciplinary focus (Li et al. 2018). Similar bibliometric studies focusing on climate change, greenhouse gas emissions, and food security have also used the Web of Science database (Chen et al. 2023; Cheng et al. 2023; Sarker et al. 2023). The literature search generated 3673 candidate articles. The initial candidate articles were screened based on their titles and abstracts under the assumption that information core to the study would be captured in these sections. Following this preliminary review, 149 articles specifically addressing agricultural GHG measurements and mitigation were selected. It was determined that title and abstract screening alone might not sufficiently reflect the content relevant to the study's objectives, potentially leading to the inclusion of many irrelevant articles. Consequently, the full articles were downloaded and reviewed. Table S2 summarises the inclusion and exclusion criteria. Only articles published between 2010 and 2023 were considered, as significant research on agricultural GHG emissions in Southern Africa began emerging in the early 2010 s. Articles published before 2010 were thus deemed less relevant. The focus was on articles related to agricultural GHG measurements, excluding those that covered broader climate change topics. The inclusion criteria also required that the research be conducted specifically in the Southern African region, and journals not relevant to agriculture were disregarded.

After reviewing the full texts, 109 studies met the eligibility criteria and were included in the analysis. The excluded studies did not meet the criteria due to reasons such as being non-empirical, not adequately addressing GHG measurements, being published before 2010, or having a geographic focus outside southern Africa. Only original research articles were included in the study to focus on primary data, which provides detailed methodologies, analysis, and results. Review articles were excluded because they summarise existing research without offering new empirical evidence. Figure S1 illustrates the process used to identify relevant studies for the scoping review and shows the number of articles excluded at each stage.

To identify the main authors involved in agricultural GHG gas research, as well as the research clusters, collaboration networks, and research themes, bibliometric analysis was conducted using VOSviewer software. VOSviewer software is widely used in academic research (Le et al. 2018; Sweileh 2020; Li and Song 2022; Cheng et al. 2023) because of its unique advantages in literature keyword analysis, cluster analysis, and hotspot identification. The VOSviewer software also enabled the creation of co-occurrence knowledge maps of the authors and institutions involved. Additionally, country contributions and research themes were examined by manually extracting data on general information such as

study location, research focus, agricultural activities, and species involved.

To ensure the accuracy and reliability of the VOSviewer-generated bibliometric analysis, first, all retrieved publications were exported as an EndNote file and independently reviewed by two researchers specialising in agricultural GHG research to confirm that the articles aligned with the study's scope. Second, the publication records of the top 10 most active authors were cross-checked against research outputs on their Google Scholar profiles. Third, during the stakeholder consultation, experts reviewed and discussed the bibliometric findings, assessing whether the identified research clusters and institutional linkages accurately reflected the collaboration patterns. Any discrepancies or missing key contributors were noted and used to refine the interpretation of results.

Survey with key researchers

To complement the literature review, we designed a structured online survey targeting researchers actively engaged in agricultural GHG research in southern Africa. The survey was distributed to 82 researchers identified through literature review, institutional affiliations, and professional recommendations. The researchers were selected across nine Southern African countries, and 47 responses were received (57% response rate). Among the 47 respondents, the majority (28) were from South Africa. Other contributing countries included Mozambique (5), Zimbabwe (4), Zambia (3), Malawi (2), Eswatini (2), Botswana (1), Namibia (1), and Lesotho (1). The respondents represented diverse research themes, including livestock, soil health, crops, and pastures. The questionnaire covered the nature of existing projects, institutional capacities, availability of research infrastructure, existing funding mechanisms, and areas that may need further support. The collected data was analysed using descriptive statistics to identify major trends and challenges in agricultural GHG research.

Stakeholder consultation workshop

A stakeholder consultation workshop to validate the findings and gather stakeholder perspectives was held in March 2023 in Pretoria, South Africa. The workshop was conducted using a hybrid approach, incorporating both in-person and virtual participation. The workshop brought together 80 participants, including researchers and representatives from government departments/ministries, international organisations, the private sector, and farmers' organisations. Of the 47 researchers who participated in the survey, 25 were purposively selected to attend the stakeholder workshop. This selection was based on their expertise, research contributions, and institutional representation.

Discussions focused on refining research priorities, identifying collaboration opportunities, and proposing actionable strategies for improving agricultural GHG research in the region. Thematic analysis of stakeholder inputs provided additional qualitative insights to supplement the literature review and survey findings. The workshop's outcomes contributed to developing an integrated framework to enable co-evolution of research governance and research activities, with ongoing mechanisms for stakeholder engagement.

Results

The results provide an overview of key researchers, institutional contributions to research, thematic areas of focus, research capacity, available infrastructure, and the challenges faced in generating scientific evidence.

Research themes and collaborations

VOSviewer software was used to analyse author contributions and collaborative networks in agricultural affiliation institutions that have contributed at least three documents. Figure 1 shows the co-authorship network between authors that have contributed at least three documents. The authors' cooperative network diagram revealed eight main author clusters. These research clusters operate independently, with minimal interconnections between them, suggesting a trend of disciplinary-focused research. Half of the clusters (clusters 2, 5, 6, and 8) focus on livestock emissions. Cluster 1 studies the GHG emissions from crops and soils while Cluster 3 focuses on soil carbon sequestration. Cluster 7 is primarily concerned with manure management.

Figure 2 shows the co-authorship network between authors' affiliation institutions that have contributed at least two documents. University of Pretoria is the largest node indicating its significant role in agricultural GHG research. The authors affiliated with this institution have a strong co-authorship network with authors affiliated with the Agriculture Research Council Outeniqua Research farm, Rothamsted Research, University of Free State, and University of Montpellier. The analysis of institutional collaborative networks also revealed that research institutions in this field are limited and dispersed, lacking a large-scale collaborative network.

The contribution of Southern African countries to research on agricultural GHG research was analysed. Country-specific analysis indicated that research efforts are mainly concentrated in South Africa (60%), which has the strongest research influence in the region. Other Southern African countries contribute relatively less to agricultural GHG research.

Fig. 1 Author contribution and collaborative networks of research teams involved in agricultural greenhouse gas research in Southern Africa. Research clusters identified through cluster analysis are distinguished by colour and numbered from 1 to 8. Clusters 2, 5, 6, and 7 focus on livestock emissions and management; Cluster 1 on crops and soil emissions; Cluster 3 on soil carbon sequestration; Cluster 4 on soil health; and Cluster 8 on manure management

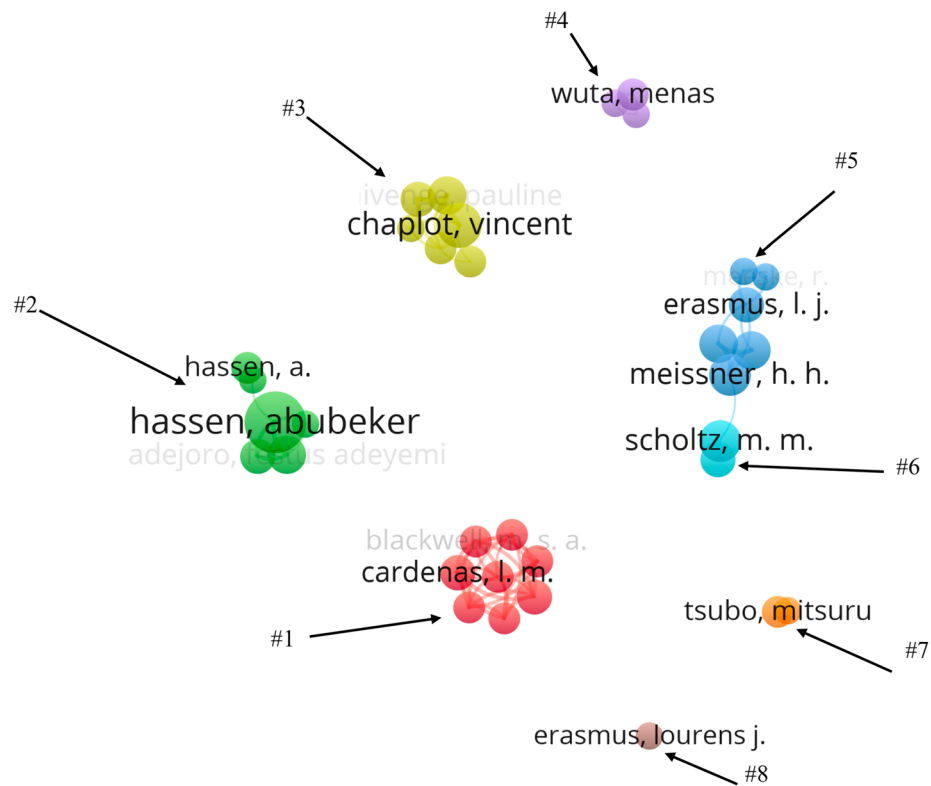
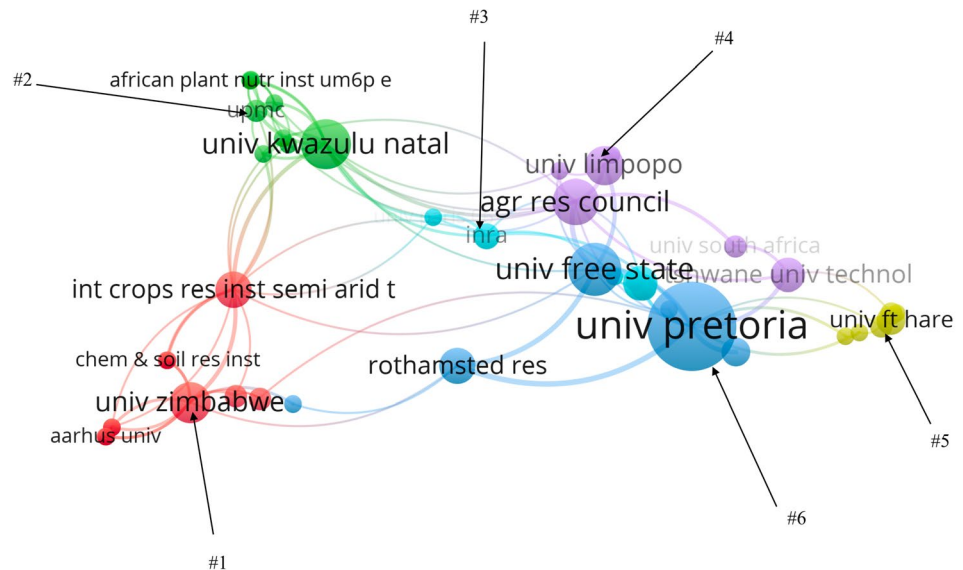


Fig. 2 Institutional collaborative network in agricultural greenhouse gas research in Southern Africa. Collaborative networks identified through cluster analysis are distinguished by colour and numbered from 1 to 6. Cluster 1 is led by the University of Zimbabwe and regional partners; Cluster 2 by the University of KwaZulu-Natal; Cluster 3 by the University of the Free State; Cluster 4 by the Agricultural Research Council of South Africa; Cluster 5 by the University of Fort Hare; and Cluster 6 by the University of Pretoria



Thematic areas addressed by the research

The articles retrieved for the scoping review were thematically analysed. About 53% of the articles focused on livestock production, while the remainder covered soils,

crops, and pastures. The research themes were identified, validated, and refined during the stakeholder consultation workshop. A total of 58 articles under livestock emissions were retrieved. The content review revealed that the studies mainly focused on:

- Modelling and estimation of net greenhouse gas emissions in farming systems (12 articles)
- Evaluation of the methanogenic potential of feedstuffs (10 articles)
- Use of tannin and other bioactive plant extracts as anti-methanogenic feed additives (10 articles)
- Improving the digestibility of low-quality forages through fibrolytic enzyme inclusion, fat or oil supplementation, and dietary nitrate or urea (9 articles)
- The carbon footprint of extensive beef production (7 articles)
- Breed evaluation in terms of feed intake and methane emission, focusing on indigenous or adapted genotypes (6 articles)

This broad thematic coverage indicates a strong research capability in these areas. However, there was limited attention to manure management (2 articles) adopting sulfur hexafluoride (SF6) technique (1 article), and GHG inventory development (1 article). Studies on the methanogenic potential of feedstuffs mainly used *in vitro* methods for estimating methane production. Enteric methane emissions were also measured *in vivo* using direct methods such as open-circuit respiration chambers (8 studies), the SF6 technique (1 study), and the open-path laser technique (1 study).

Practices to reduce enteric methane emissions included using plant extracts from tannins and other bioactive compounds, fat or oil supplementation, as well as enhancing the digestibility of low-quality forages with the addition of fibrolytic enzymes, dietary nitrate, or urea. Studies on net GHG emissions modelling were conducted in both commercial and communal sectors. Only two studies addressed ruminant manure GHG emissions, with no research on any other manure management systems like slurry tanks, composting, or anaerobic digesters.

A total of 51 articles were retrieved under the soils, crops, and pastures emissions. The content review revealed that studies mainly focused on:

- Soil GHG emissions (N₂O, CH₄, and CO₂; 28 articles)
- Soil carbon sequestration (11 articles)
- Rangeland management to reduce carbon emissions (8 articles)
- There were significantly fewer studies on crop emissions (4 articles)

Researchers also detailed their research and institutional capabilities including infrastructure. Table 1 outlines the existing research capabilities and highlights areas requiring further investment to advance agricultural GHG research. The table represents only South Africa, as research infrastructure and equipment for agricultural GHG studies are primarily concentrated in South African institutions. Other countries lack the necessary infrastructure and often rely on South African laboratories and facilities for sample analysis.

Prevailing challenges

Nearly 50% of the surveyed researchers reported that they currently do not have funding for research. Many researchers without funding indicated that they only received financial support during their doctoral studies and have not been able to conduct new research since completing their doctoral studies. Others indicated that the funding they receive is limited to covering research costs and is insufficient for infrastructure investment. The reliance on external institutions for analytical aspects further exacerbates research costs, highlighting the critical need to address funding challenges in agricultural GHG research.

A significant proportion of respondents (~60%) indicated that their institutions lack the necessary infrastructure and equipment. Consequently, they often must source analytic

Table 1 Agricultural greenhouse gas (GHG) research and infrastructure-related capability

Analysis	Infrastructure/equipment
In vitro gas production of feedstuffs	Rumen cannulated animals, incubator, gas chromatography
Measurement/estimation of enteric emissions from livestock	Open-circuit respiratory chambers GrowSafe system Laser methane detector Sulfur hexafluoride method
Measurement of emissions from soil, pasture, and animal manure	Static chambers for measuring soil nitrous oxide GHG analyser and gas chromatography for measuring soil nitrous oxide Carbon emission chambers and data loggers carbon nitrogen 628 for soil carbon measuring
Modelling and estimation of net greenhouse gas emissions in farming systems	Carbon sinks in dairy systems
Farm-gate life-cycle analysis to quantify GHG emissions in farms.	Farm-gate life-cycle analysis

services from other organisations, which is a very expensive alternative. One institution reported that its existing equipment for in vitro methane measurement is over 10 years old and is in urgent need of a major upgrade.

Stakeholder recommendations

Stakeholders at the workshop provided several key recommendations to enhance communication and collaboration among regional researchers, policymakers, industry, and farmers. These recommendations aim to ensure that existing research effectively serves or connects with stakeholders.

The primary recommendation is to align research efforts with the conditions, needs, and priorities of farmers and other stakeholders. This includes conducting baseline assessments to deeply understand farmers' requirements and ensuring that research recommendations are grounded in real-world needs rather than theoretical frameworks. By adopting this approach, researchers can tailor their studies to address practical challenges faced by farmers, thereby increasing the relevance and impact of their findings.

Stakeholders emphasised the importance of fostering collaborative partnerships throughout the research process. They suggested that farmer associations and other relevant groups should be actively involved in research projects from the outset. This collaboration allows researchers to leverage the wealth of knowledge and experience possessed by these stakeholders, leading to more holistic and contextually relevant research outcomes. Moreover, research outputs should be formulated in an easily understandable format to facilitate adoption by farmers and other end-users.

The third recommendation highlights the need for a unified government mandate and policy integration to address inconsistencies in existing rules and regulations. Fragmented policies across different government departments can hinder the effective implementation of sustainable agricultural practices. Therefore, stakeholders advocate for the development of a partnership framework involving researchers, policymakers, and other relevant stakeholders. This framework would promote transdisciplinary research and align it with national master plans, ensuring coherence and consistency in policy formulation and implementation. Such an integrated approach is crucial for facilitating the transition towards more sustainable agricultural practices.

Discussion

The results of this paper underscore the urgent need for a dedicated collaborative forum to foster regional cooperation and advance agricultural GHG research in southern Africa. The study enriches the ongoing discourse of low-emission and climate-resilient food systems by identifying key actors,

thematic areas, research capacity, available infrastructure, and prevailing challenges in agricultural GHG research in southern Africa.

The network map revealed a significant gap in agricultural GHG studies within Southern Africa, with less than 40% of publications originating from countries other than South Africa. This suggests that the agricultural GHG research ecosystem is fragmented and dominated by South African contributions. While this highlights South Africa's research leadership and capacity, it also underscores the marginal participation of other Southern African countries. This imbalance has significant implications for regional knowledge production, policy formulation, and equitable resource distribution. Countries with limited research presence may struggle to develop context-specific mitigation strategies due to a lack of locally generated data and expertise. Addressing this disparity requires intentional efforts to expand research networks and strengthen capacity-building.

One of the most striking findings from the network maps is the high level of fragmentation in agricultural GHG research across the region. The visual representation indicates that research institutions and individual researchers operate within distinct clusters with minimal cross-collaboration. Various research teams tend to operate independently within their respective fields. This disciplinary and institutional separation limits knowledge exchange and prevents the pooling of resources and expertise. Such fragmentation leads to inefficiencies, including duplication of efforts and missed opportunities for synergies in research methodologies, data collection, and policy recommendations.

Fragmentation of research has previously been identified as a major barrier to transformative research in food systems (Kok et al. 2019). The siloed nature of current research efforts fails to adequately address persistent food system challenges due to a lack of integration and consideration of trade-offs, unintended consequences, and systemic feedback loops (Kang and Banga 2013; El Bilali 2019). Addressing this challenge requires a shift from siloed research and fostering transdisciplinary collaboration networks (Jordan et al. 2023; Munialo et al. 2023). This involves encouraging researchers from diverse disciplines to work together in a consortium towards shared goals and integrating multiple perspectives from various fields to address complex challenges. Transdisciplinary research is important considering the complexity of food system challenges, which require multifaceted solutions that incorporate viewpoints from different disciplines (Kok et al. 2019; den Boer et al. 2021). It should also involve non-academic actors such as policymakers, business leaders, and farmers, who play crucial roles in food systems (den Boer et al. 2021).

The network map further revealed the lack of a significant regional collaboration network among the institutions. Without well-established networks, research findings struggle to

inform policy decisions effectively. Moreover, limited collaboration reduces the likelihood of securing large-scale international funding, as funders often prioritise well-coordinated, multi-institutional projects with broad impact. Pouris and Ho (2014) also reported low collaborative research across African institutions, attributing this to low funding, inadequate support, lack of collaborative networks, government disinterest in research, and lack of mentorship. They suggest establishing regional research and innovation systems, or an 'African Research Union' would better serve Africa's science and developmental needs (Pouris and Ho 2014). Other studies have shown that a large collaborative network among regional institutions enhances learning and contributes to solving local complex problems (van der Wouden and Youn 2023). Therefore, creating a network of regional institutions is crucial for addressing the challenges facing regional food systems.

The situational analysis showed that agricultural GHG research is mostly conducted in South Africa, with limited involvement from other Southern African countries. This suggests that agricultural GHG research has not gained significant traction in other Southern African countries where infrastructure and capacity are limited, less research funding is allocated nationally to GHG research, and access to international funding sources is also limited. Survey respondents and participants in the stakeholder consultation workshop cited a lack of infrastructure and funding as the main reasons for this limited engagement. Graham et al. (2022) similarly reported a low number of GHG-related studies across sub-Saharan Africa, which were also limited in focus and geographic scope. Other researchers have indicated that the limited involvement of African countries in GHG research is due to financial, infrastructural, and human resource challenges, which deter researchers from pursuing this field (van der Wouden and Youn 2023; Graham et al. 2022). This can impede progress towards sustainable food systems and development at national and regional levels. To address this, efforts should be made to raise awareness about the importance of GHG research and its relevance to national development priorities. Governments can play a key role by providing funding, policy incentives, and capacity-building initiatives. Additionally, involving regional organisations in research projects can help build research capacity, facilitate knowledge exchange between countries, and contribute to broader policy development.

The situational analysis also revealed a lack of infrastructure and funding as major barriers to enhancing research capacity and conducting high-quality scientific studies, as previously reported in the literature (Cho et al. 2023). This lack of resources forces researchers to scale back their projects, delay research activities, or pursue alternative funding sources, which limits progress in generating scientific evidence. The scarcity of funding

and infrastructure not only affects the scale and pace of research but also has broader implications for the research ecosystem. Inadequate funding and infrastructure may prevent talented researchers from pursuing academic or research careers, leading them to seek opportunities in countries or institutions with better resources and support systems, thereby contributing to a dearth of research talent, especially among early-careers researchers. den Boer et al. (2021) argue that research and innovation funding structures are misaligned, with investments unevenly distributed across sectors and disciplines, and a lack of incentives to develop holistic, integrated research and innovation approaches. Both private and public funders can support the transformative potential of research by establishing more integrated transdisciplinary and mission-driven funding programmes. By investing in research capacity building, supporting infrastructure development, and promoting collaborative and mission-driven funding approaches, stakeholders can create an enabling environment for high-quality scientific research that drives positive societal change (Kok et al. 2019).

Research infrastructure and equipment for agricultural GHG studies are primarily concentrated in South African institutions. Other Southern African countries lack the necessary infrastructure and often rely on South African laboratories and facilities for sample analysis. This highlights a significant gap in regional research capacity, reinforcing the need for investment in infrastructure, equipment, and capacity-building initiatives across the region to enable independent research in other countries.

The research capacity demonstrated in the findings reveals a significant depth of knowledge and expertise in various aspects of GHG emissions within farming systems. This research capacity spans multiple research themes known to mitigate agricultural GHG emissions, including animal feed management, diet formulation, rumen manipulation, and soil carbon sequestration (Arndt et al. 2022; Graham et al. 2022; Rodrigues et al. 2023).

Despite the substantial research capacity, there are notable gaps and limitations. While there has been research on methane emissions from livestock and soil carbon sequestration, studies integrating multiple emission sources within farming systems are lacking. There is a need for research that incorporates the full life-cycle analysis of emissions from soil, livestock, crop production, and waste management. In addition, manure management is a significant source of GHG emissions in agriculture (Won et al. 2020; Graham et al. 2022), yet there is absence of suitable facilities for measuring emissions from manure treatment processes limits the understanding of effective mitigation strategies in this area. Future research should explore innovative manure management strategies that reduce emissions while enhancing soil fertility.

Beyond research capability, there are significant gaps between research and policy (Opejin et al. 2020). This study revealed a noticeable scarcity of research focused on policy across the thematic areas. Other researchers have also reported gaps between research and policy in transforming food systems (Kok et al. 2019; den Boer et al. 2021; Munialo et al. 2023). This gap could be partly attributed to low collaboration between research and policy institutions (Munialo et al. 2023). Given that decisions impacting food systems are made across multiple governance levels from local to global, there is a need for mechanisms to link researchers and policymakers. Collaboration with policy institutions can facilitate the translation of research findings into policy frameworks, ensuring that research evidence informs decision-making (Munialo et al. 2023).

The stakeholders' proposed solutions emphasise several crucial actions for advancing agricultural GHG research. The first key recommendation highlights the importance of aligning research efforts with the conditions, needs, and priorities of farmers and other stakeholders, as emphasised, in previous studies (Middendorf et al. 2020). Another crucial aspect highlighted by stakeholders is the promotion of collaborative partnerships throughout the research process. Grill (2021) argues that improving stakeholders' collaboration is still a desirable objective in research priority setting as this allows actors to use one voice which is an important condition for success. In addition, Thornton et al. (2018)'s framework for priority setting in climate-smart agriculture research posits that engaging stakeholders throughout the research process ensures that priorities align with the needs and preferences of end-users, including farmers, policymakers, and other relevant actors. The last recommendation by the stakeholders highlights the need for a unified government mandate and policy integration to address contradictions in existing policies as also previously reported in the literature (Newell et al. 2019). This is important considering that fragmented policies across different government departments/ministries can hinder the effective implementation of sustainable agricultural practices (Newell et al. 2019).

The way forward

The situational analysis highlighted that the current landscape of agricultural GHG research in Southern Africa is inadequate for addressing urgent systemic challenges of GHG emissions management and quantification in food systems. This inadequacy is due to fragmented research in science and policy, a lack of funding and infrastructure, and limited involvement of stakeholders. Despite these challenges, there is significant potential for transformative change because of the significant depth of knowledge and expertise in various aspects of GHG emissions. Addressing the challenges requires a concerted effort from

governments, funding agencies, research institutions, and other stakeholders (Herrero et al. 2021).

Learning from other countries can provide valuable insights into overcoming challenges highlighted in this situational analysis. For example, New Zealand's collaborative initiatives demonstrate how coordinated efforts among diverse stakeholders can lead to impactful outcomes in mitigating agricultural GHG emissions and promoting sustainable practices (AgResearch 2022). Their model involves cooperation between the government, research institutions, and the farming community (AgResearch 2022). Through strategic multisectoral collaboration and resource pooling, New Zealand has effectively addressed research fragmentation and leveraged its expertise to drive innovation and development in agricultural GHG mitigation (Grieco et al. 2019; Graham et al. 2022).

Climate-smart agriculture initiatives in East Africa also demonstrate the benefits of integrating multiple stakeholders into a robust partnership model (Kirina et al. 2022). These initiatives have promoted sustainable agricultural practices that enhance resilience to climate change while reducing emissions (Kirina et al. 2022). They emphasise the importance of aligning research with the needs of farmers and policymakers, ensuring that scientific findings are translated into actionable practices. The success of these initiatives highlights the critical role of stakeholder engagement and effective dissemination of research outcomes.

Progress has been made toward establishing a regional collaborative forum promoting transdisciplinary and multisectoral collaboration in Southern Africa. The Qinisa project, a regional collaborative project aimed at strengthening low-emission climate-resilient food systems in southern Africa, has been established. This project will connect researchers across disciplines, institutions, countries, and regions to conduct cutting-edge research on low-emission and climate-resilient food systems. The project will involve research institutions, academia, policymakers, supporting industries, the private sector, farmer organisations, and international organisations. Extensive stakeholder consultations are already underway. A central component of the Qinisa project is the development of an information and advisory portal to facilitate information sharing and knowledge exchange among stakeholders. This portal will connect ongoing and planned agricultural GHG-related research activities and investments, fostering collaboration, and reducing fragmentation. Additionally, the project will support the dissemination of scientific findings to policymakers and promote the adoption of innovations by producers. Through enhanced collaboration and innovation, the Qinisa project is poised to pave the way toward low-emission and climate-resilient food systems.

Limitations of the study

There were a few limitations to the study. First, the study primarily focuses on nine Southern African countries, with a significant research bias toward South Africa, which has the highest research output in the region. As a result, findings may not be fully representative of other countries with limited research capacity, leading to a skewed understanding of regional trends. Second, the bibliometric analysis relies exclusively on the Web of Science Core Collection, which excludes non-indexed regional journals, institutional reports, and grey literature that may contain relevant research. This limitation could contribute to an incomplete picture of the research landscape. Additionally, the study applies strict inclusion criteria, considering only peer-reviewed original research articles, thereby excluding review papers and conference proceedings that may provide valuable insights. Addressing these limitations in future research could enhance the robustness and applicability of findings.

Conclusion

The research examined the current state of agricultural GHG research and collaboration in Southern Africa. Despite some positive developments, several challenges persist that hinder the progress of agricultural GHG research in the region. Key obstacles include fragmented research efforts, limited multi-institutional collaboration, insufficient involvement of countries other than South Africa, and a lack of funding and infrastructure. Additionally, there is a significant disconnect between research and policy, which hampers the translation of research findings into practical policy measures.

The situational analysis highlighted the urgent need for transdisciplinary collaborative efforts, involving not only academic researchers but also policymakers, industry, and farmer associations, to address the challenges facing agricultural GHG emissions research. Establishing a transdisciplinary regional research collaboration programme, in partnership with other countries, will provide a solid foundation of scientific knowledge and information. This foundation is crucial for helping decision-makers and stakeholders navigate the complexities of identifying and implementing agricultural GHG emissions reduction strategies.

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Data availability The data presented in this study are available on request from the corresponding author.

Declarations

Ethics approval The study was approved by the Faculty of Natural and Agricultural Sciences Research Ethics Committee of the UNIVERSITY OF PRETORIA (NAS 246/2022 1 November 2022).

Consent to participate Informed consent was obtained from all subjects involved in the study.

Conflict of interest The authors declare no competing interests.

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References

- AgResearch (2022) <https://www.agresearch.co.nz/assets/Uploads/Report-PDFs/AgResearch-Annual-Report-2022.pdf>. Accessed 12 June 2024
- Arndt C, Hristov AN, Price WJ, McClelland SC, Pelaez AM (2022) Full adoption of the most effective strategies to mitigate methane emissions by ruminants can help meet the 1.5 C target by 2030 but not 2050. PNAS 119:e2111294119. <https://doi.org/10.1073/pnas.2111294119>
- Chen G, Bai J, Bi C, Wang Y, Cui B (2023) Global greenhouse gas emissions from aquaculture: a bibliometric analysis. Agric Ecosyst Environ 348:108405. <https://doi.org/10.1016/j.agee.2023.108405>
- Cheng P, Tang H, Lin F, Kong X (2023) Bibliometrics of the nexus between food security and carbon emissions: hotspots and trends. Environ Sci Pollut Res 30:25981–25998. <https://doi.org/10.1007/s11356-022-23970-1>
- Chevallier R (2023) Strengthening Africa's climate-smart agriculture and food systems through enhanced policy coherence and

- coordinated action. *S Afr J Int Aff* 30:595–618. <https://doi.org/10.1080/10220461.2024.2318712>
- Chevallier R, Mabuza M, Thornton P, Cramer L (2021) Strengthening Southern Africa's NDCs to bolster farmers' interests. *Policy Insights*. <https://www.jstor.org/stable/pdf/resrep32594.pdf>. Accessed 22 August 2024
- Cho MA, Ramoelo A, Sibanda LM (2023) Exploring the integration of the land, water, and energy nexus in sustainable food systems research through a socio-economic lens: a systematic literature review. *Sustainability*. 15:16528. <https://doi.org/10.3390/su152316528>
- Davis-Reddy CL, Vincent K (2017) *Climate risk and vulnerability: a handbook for southern Africa*, 2nd edn; Council for Scientific and Industrial Research, Pretoria
- den Boer ACL, Kok KPW, Gill M, Breda J, Cahill J (2021) Research and innovation as a catalyst for food system transformation. *Trends Food Sci Technol*. 107:150–156. <https://doi.org/10.1016/j.tifs.2020.09.021>
- El Bilali H (2019) Research on agro-food sustainability transitions: where are food security and nutrition? *Food Secur* 559–577. <https://doi.org/10.1007/s12571-019-00922-1>
- Graham MW, Butterbach-Bahl K, du Toit CL, Korir D, Leitner S (2022) Research progress on greenhouse gas emissions from livestock in sub-Saharan Africa falls short of national inventory ambitions. *Front Soil Sci* 2:927452. <https://doi.org/10.3389/foisoil.2022.927452>
- Grieco E, Bombelli A, Adeyemi C, Kebe I, Bamba M (2019) Report on needs and gaps in Africa in terms of data, knowledge, and RI with recommendations for a joint EU-Africa Research & STI agenda on GHG observations focusing on land use and land use change under a changing climate. https://www.seacrifog.eu/fileadmin/seacrifog/Deliverables/Deliverable_1.1.pdf. Accessed 12 June 2024
- Grill C (2021) Involving stakeholders in research priority setting: a scoping review. *Res Involv Engagem* 7:1–18. <https://doi.org/10.1186/s40900-021-00318-6>
- Herrero M, Mason-D'Croz D, Thornton PK, Fanzo J, Rushton J (2021) Livestock and sustainable food systems: status, trends, and priority actions. In von Braun J, Fresco KALO, Hassan MHA (eds). Springer, Cham, Switzerland. pp 375–400
- IPCC (2017) Special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (SR2). https://www.ipcc.ch/site/assets/uploads/2018/07/sr2_background_report_final.pdf. Accessed 22 Aug 2024
- IPCC (2022) Climate change impacts, adaptation, and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change In Pörtner HO, Roberts DC, Tignor M, Poloczanska ES, Mintenbeck K (eds). Cambridge University Press, Cambridge and New York, pp 3056
- Jordan NR, Valley W, Donovan D, Clegg DJ, Grossman J (2023) Scaffolding collective agency curriculum within food-systems education programs. *Front Sustain Food Syst* 18:111945. <https://doi.org/10.3389/fsufs.2023.1119459>
- Kang MS, Banga SS (2013) Global agriculture and climate change. *J Crop Improv* 27:667–692. <https://doi.org/10.1080/15427528.2013.845051>
- Kirina T, Groot A, Shilomboleni H, Ludwig F, Demissie T (2022) Scaling climate smart agriculture in East Africa: experiences and lessons. *Agronomy* 12:820. <https://doi.org/10.3390/agronomy12040820>
- Kok KPW, den Boer ACL, Cesuroglu T, van der Meij MG, de Wildt-Liesveld R (2019) Transforming research and innovation for sustainable food systems—a coupled-systems perspective. *Sustainability* 11:7176. <https://doi.org/10.3390/su11247176>
- Lamb WF, Grubb M, Diluio F, Minx JC (2022) Countries with sustained greenhouse gas emissions reductions: an analysis of trends and progress by sector. *Climate Policy* 22:1–17. <https://doi.org/10.1080/14693062.2021.1990831>
- Leahy S, Clark H, Reisinger A (2020) Challenges and prospects for agricultural greenhouse gas mitigation pathways consistent with the Paris Agreement. *Front Sustain Food Syst* 4:69. <https://doi.org/10.3389/fsufs.2020.00069>
- Li J, Song W (2021) Food security review based on bibliometrics from 1991 to 2021. *Foods* 11:3915. <https://doi.org/10.3390/foods11233915>
- Li K, Rollins J, Yan E (2018) Web of Science use in published research and review papers 1997–2017: a selective, dynamic, cross-domain, content-based analysis. *Scientometrics* 115:1–20. <https://doi.org/10.1007/s11192-017-2622-5>
- Middendorf BJ, Prasad PV, Pierzynski GM (2020) Setting research priorities for tackling climate change. *J Exp Bot* 71:480–489. <https://doi.org/10.1093/jxb/erz360>
- Munialo S, Onyango CM, Lukachi JA, Wasonga OV, Maina JG (2023) Gaps and opportunities in research on food systems; a micro-institutional analysis of the University of Nairobi. *Front Sustain Food Syst* 7:1125094. <https://doi.org/10.3389/fsufs.2023.1125094>
- Negra C, Remans R, Attwood S, Jones S (2020) Sustainable agri-food investments require multi-sector co-development of decision tools. *Ecol Indic* 110:105851. <https://doi.org/10.1016/j.ecolind.2019.105851>
- Nelson E, Dodd W (2017) Collaborating for community food security: emerging scholar participation in a community-university partnership. *Action Res* 15:402–423. <https://doi.org/10.1177/1476750316656041>
- Newell P, Taylor O, Naess LO, Thompson J, Mahmoud H (2019) Climate smart agriculture? Governing the sustainable development goals in Sub-Saharan Africa. *Front Sustain Food Syst* 3:55. <https://doi.org/10.3389/fsufs.2019.00055>
- Nhamo G (2018) UNFCCC decision on agriculture: Africa must continue prioritising adaptation in the Talanoa Dialogue and (I) NDC processes. *S Afr J Int Aff* 25:281–299. <https://doi.org/10.1080/10220461.2018.1522275>
- Okner T (2015) The role of research institutions in civic science & sustainable development diplomacy. CCAFS Report. <https://cgspage.cgiar.org/items/b68d0823-b592-4807-83f4-738ab7f5690b>. Accessed 12 June 2024
- Opejin AK, Aggarwal RM, White DD, Jones JL, Maciejewski R (2020) A bibliometric analysis of food-energy-water nexus literature. *Sustainability* 12:1112. <https://doi.org/10.3390/su12031112>
- Pinkse J, Kolk A (2012) Addressing the climate change—sustainable development nexus: The role of multistakeholder partnerships. *Bus Soc* 51:176–210. <https://doi.org/10.1177/0007650311427426>
- Pouris A, Ho YS (2014) Research emphasis and collaboration in Africa. *Scientometrics* 98:2169–2184. <https://doi.org/10.1007/s11192-013-1156-8>
- Radeny M, Mungai C, Amwata D, Osumba J, Solomon D (2020) Climate change, agriculture, food and nutrition security policies and frameworks in Kenya. CCAFS Working Paper no. 330. Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). <https://cgspage.cgiar.org/server/api/core/bitstreams/0262e>

- [e7b-f46a-4fb4-91a0-554357da077b/content](https://doi.org/10.1016/j.agry.2018.09.009). Accessed on 12 June 2024
- Rodrigues CID, Brito LM, Nunes LJ (2023) Soil carbon sequestration in the context of climate change mitigation: a review. *Soil Syst* 7:64. <https://doi.org/10.3390/soilsystems7030064>
- SADC Regional Vulnerability Assessment and Analysis Synthesis Report. https://www.sadc.int/sites/default/files/2021-11/2015_SADC_Regional_Vulnerability_Assessment_Report_-_compressed.pdf. Accessed 12 February 2024
- Sarker MNI, Hossain B, Shi G, Firdaus RR (2023) Promoting net-zero economy through climate-smart agriculture: transition towards sustainability. *Sustain Sci* 18:2107–2119. <https://doi.org/10.1007/s11625-023-01379-0>
- Sweileh WM (2020) Bibliometric analysis of peer-reviewed literature on food security in the context of climate change from 1980 to 2019. *Agric Food Secur* 9:1–15. <https://doi.org/10.1186/s40066-020-00266-6>
- Thornton PK, Whitbread A, Baedeker T, Cairns J, Claessens L (2018) A framework for priority-setting in climate-smart agriculture research. *Agric Syst* 167:161–17. <https://doi.org/10.1016/j.agry.2018.09.009>
- Tricco AC, Lillie E, Zarin W, O'Brien K, Colquhoun H (2016) A scoping review on the conduct and reporting of scoping reviews. *BMC Med Res Methodol* 16:1–10. <https://doi.org/10.1186/s12874-016-0116-4>
- van der Wouden F, Youn H (2023) The impact of geographical distance on learning through collaboration. *Res Policy* 52:104698. <https://doi.org/10.1016/j.respol.2022.104698>
- Won S, Yoon Y, Hamid MM, Reza A, Shim S, et al. (2020) Estimation of greenhouse gas emission from Hanwoo (Korean native cattle) manure management systems. *Atmosphere* 11:845. <https://doi.org/10.3390/atmos11080845>

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