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The social, economic and environmental impact of an agroecological farming system: a case study in Phumulani Agri-village, Belfast, Mpumalanga, South Africa

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This paper demonstrates the contribution of an agroecological model to food and nutrition security and livelihood strategies in the Phumulani Agri-village (PAV), located in Belfast, Mpumalanga, South Africa. PAV is a post-mining agri-village comprised of 32 households and approximately 200 individuals. The objectives of the project were to create jobs, generate income, establish a sustainable rural livelihood model that can be replicated, and implement environmentally friendly practices focusing on soil fertility, nutrition, green energy, and water security. A mixed research methodology was used to collect quantitative and qualitative data through structured questionnaires and focus group discussion. The Sustainable Livelihood Assets framework and Sustainable Development Goals (SDGs) were used to evaluate the project's contributions. Ninety four percent of the thirty-two village household representatives and nine of the ten project beneficiaries completed questionnaires which were administered by the project manager. Findings after 24 months are based on our Sustainable Livelihood Assets framework and the Sustainable Development Goals (SDGs), show that the project has contributed to Economic Capital and SDGs 1 and 8, specifically addressing poverty, promoting decent work and economic growth by creating decent jobs and reliable income streams. The project also contributed to Human Capital and SDGs 2 and 3 through improved household food security and access to food. In addition, the intervention supported SDG Goal 4, Quality Education, through an integrated and accredited training and skills development programme. The initiative promoted Physical Capital and SDGs 6 and 7 by incorporating green infrastructure such as biogas digesters, a commercial wormery and boreholes with solar pumps. The findings confirm the effectiveness of agroecology in community and social development, demonstrating its positive social, economic, and environmental outcomes. The model can be replicated by government and corporate entities, potentially influencing policies and support programs that support agroecology in South Africa.

KEYWORDS

Agroecology, food security, livelihoods, Phumulani Agri-village, post-mining

1 Introduction

Many vulnerable communities in South Africa face challenges related to food and nutrition insecurity, poverty, and economic and environmental crisis, especially in terms of access to clean, safe water and energy (Govender et al., 2017; Mabhaudhi et al., 2018; Schwarz et al., 2020; Nyiwul, 2021). The effects of poverty and food insecurity go beyond nutrition, leading to higher risks of infectious diseases, gender-based violence, and substance abuse (Mtintsilana et al., 2022). Moreover, both rural and urban impoverished regions in South Africa face widespread inadequate nutrition and food insecurity, largely due to factors such as unemployment (Mbhenyane and Tambe, 2024). Despite South Africa's efforts to support vulnerable populations through social protection programs, challenges remain, such as the aftermath of the COVID-19 pandemic (Lekganyane, 2024). Community health workers are essential in delivering health and psychosocial services to households and disadvantaged communities in South Africa, playing a crucial role in reducing health disparities (Thomas et al., 2021). The economic fallout from lockdowns and restrictions led to increased poverty levels, which, in turn, heightened food insecurity among households as economic activities were severely disrupted (Patrick et al., 2021; Vyas-Doorgapersad et al., 2023). Studies indicate that the pandemic has resulted in a significant rise in food and nutrition insecurity, with many households struggling to meet their basic needs (Wegerif, 2021).

Food insecurity remains a major health risk in the country, emphasizing the need for comprehensive interventions (Napier et al., 2018; Dlamini et al., 2023). While increasing food availability may address caloric deficiencies, it does not necessarily ensure access to nutritionally appropriate or safe foods (Burchi and De Muro, 2015). The issue is more complex, as food insecurity is not only about quantity but also quality, thus ensuring that people have access to balanced diets that promote health rather than exacerbate it through exposure to harmful substances such as pesticides or nutrient-poor, processed foods (Stahacz et al., 2024). The focus of this study extends beyond food quantity to encompass sustainable, health-conscious food production systems that prioritize both environmental and human well-being.

In South Africa, women of childbearing age face additional risks that can impact their capacity to cope with public health crises, highlighting the role of social factors in food security (Ware et al., 2021). To tackle food insecurity, a comprehensive strategy is necessary; one that involves utilizing indigenous food sources and implementing sustainable farming methods (Toit et al., 2023). The complex issues of food and nutrition insecurity, poverty, and environmental challenges in South Africa necessitate a comprehensive approach that tackles not just food access but also the broader socio-economic factors that contribute to vulnerability. Climate change further exacerbates these challenges (Ncisana et al., 2023). Climate change further exacerbates these challenges by disrupting agricultural production, increasing the prevalence of droughts and floods, and straining water resources, which in turn intensify food scarcity and undermine livelihoods, particularly for vulnerable communities (Amoah and Simatele, 2021; Mthembu and Hlophe, 2021; Zenda et al., 2024). Masipa (2017) and

Ngumbela et al. (2020) assert that these difficulties offer opportunities to apply appropriate and robust methodologies to assess and evaluate projects that will generate findings to influence suitable interventions.

Sands et al. (2023) argue that while the agroecological concept has evoked much scholarly work, there is a need for more practical application and evaluation. A lack of readily accessible data, including real-time data, hinders the ability to make swift and well-informed decisions on policies regarding agroecology. Agroecology is a comprehensive and cooperative method that seeks to shift to sustainable food systems by harmonizing with nature and adapting to local contexts, thereby shaping agriculture and food systems in an environmentally sustainable manner (Tataridas et al., 2023; James et al., 2023). This transition entails building robust markets for agroecologically grown foods, fostering social solidarity economies, and raising public awareness about agroecological practices (Wezel et al., 2020). Having reliable data, knowledge, and best practices in agroecology is essential for farmers to make well-informed decisions (Dushyant, Sharma, et al., 2024). Utilizing both existing and new data sources can offer valuable insights to farmers, scientists, and policymakers, thereby enhancing agricultural production while reducing environmental effects.

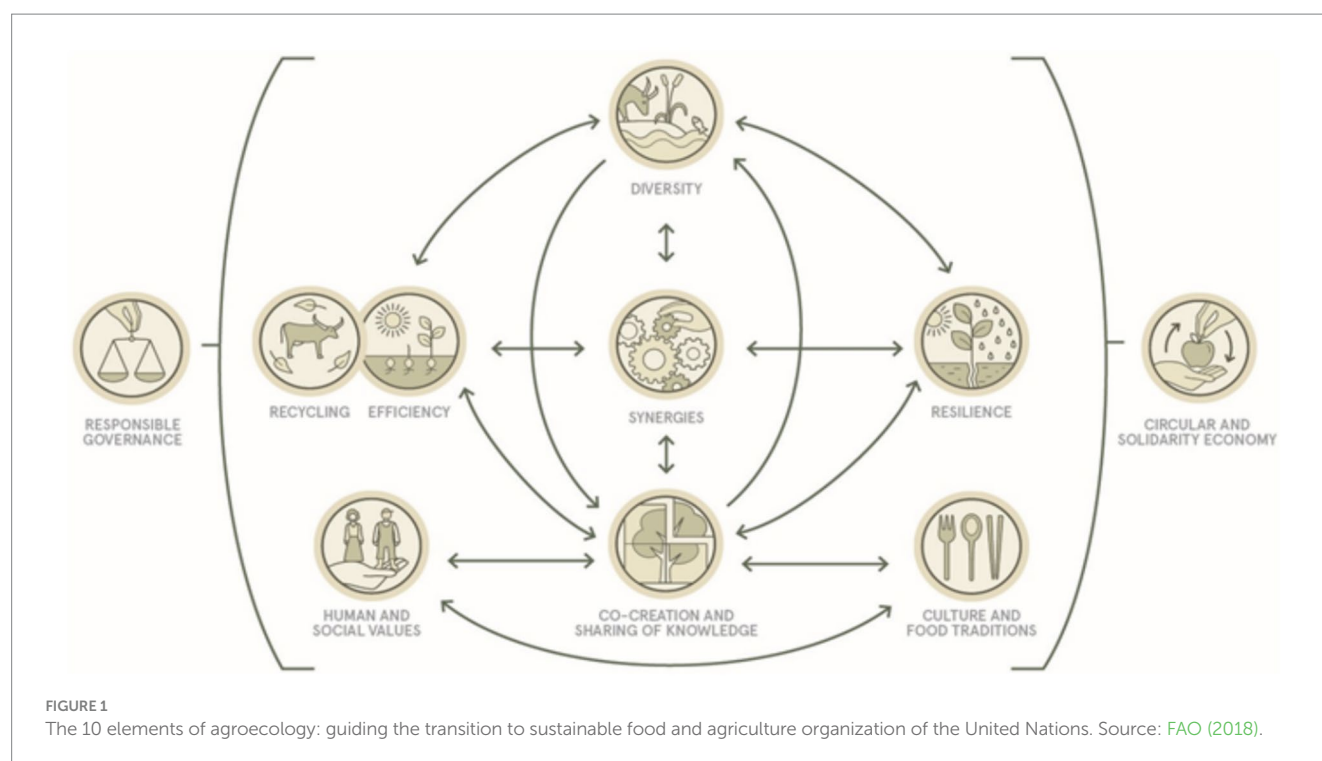
Despite the growing body of literature supporting the benefits of agroecological farming, huge research gaps persist that hinder a comprehensive understanding of its full impact. One notable gap is the scarcity of long-term studies that track the social, environmental, and economic impacts of agroecological practices over extended periods. Most existing studies are short-term and do not capture the sustained effects on ecosystems and communities. This limitation makes it challenging to fully assess the potential of agroecological practices in promoting sustainable agriculture and resilient food systems. This paper aims to demonstrate an initial impact of an agroecological farming model and its contribution to having a tangible social, environmental, and economic impact, with a strong focus on improved food and nutrition security and livelihoods.

This study addresses a critical gap in agroecology and rural development literature by providing empirical evidence on how an agroecological framework, when combined with entrepreneurial interventions, can enhance both ecological resilience and economic sustainability. Existing research often focuses on the environmental and productivity aspects of agroecology but overlooks the socio-economic dimensions critical for long-term viability. By integrating an analysis of infrastructure needs, social capital formation, and financial sustainability, this study offers a holistic perspective that can inform future agroecological models and policy design.

2 Conceptual frameworks

According to the Food and Agriculture Organization (FAO), the 10 Elements of Agroecology resulted from a multi-stakeholder process intended to generate a system and re-design framework to be optimized and adapted to local contexts (Wezel et al., 2020). This framework was developed between 2015 and 2019. Prominent themes of agroecology include recycling, efficiency, diversity, resilience, and synergies as central ecological features (Wang, 2022). Nevertheless, calls in regional meetings for reinforcing social and political aspects of agroecology were also strong. Thus, an additional five elements were included: co-creation of knowledge, human and social values, culture and food traditions, responsible governance, and circular and

Abbreviations: CPA, Community property association; FAO, Food and agriculture; PAV, Phumulani Agri-village; SDGs, Sustainable development goals; SLA, Sustainable development goals.



solidarity economy ([Barrios et al., 2020](#)). The FAO's framework of 10 elements offers a perspective to comprehend and implement key principles of agroecology, aiding the shift towards more sustainable farming methods ([Figure 1](#)).

Agroecology has gained considerable attention as a comprehensive method for transitioning food systems towards sustainability ([James et al., 2023](#)). The Food and Agriculture Organization (FAO) has played a key role in advancing agroecology worldwide, highlighting its capacity to tackle numerous food system challenges and the Sustainable Development Goals ([Anderson et al., 2019](#)). Efficiency, a fundamental principle of agroecology, is emphasized as vital for the ecological and economic sustainability of agricultural production systems ([Falconnier et al., 2023](#)). Furthermore, the importance of biodiversity is highlighted in agroecology, encompassing the integration of crops and livestock and the cultivation of various crop varieties tailored to local ecosystems ([Owoputi et al., 2022](#)). By adopting agroecology, stakeholders seek to reform food and agriculture systems by tackling fundamental issues comprehensively, providing holistic and sustainable solutions ([Siegener et al., 2019](#); [Novaes, 2024](#)). Agroecology provides a framework for policymakers, practitioners, and stakeholders to plan, manage, and assess agroecological systems, aiding in the practical implementation of agroecology ([Dagoudo et al., 2023](#)).

3 Study area

Phumulani Agri-village (PAV) is in Belfast, Mpumalanga, South Africa. The village comprises 32 households and approximately 200 individuals and is situated close to several surrounding communities, schools, farms, mining communities and small businesses. Belfast experiences a subtropical highland climate with mild summers and chilly, dry winters. The average annual precipitation is 674 mm, with most of the rainfall occurring during the summer

months ([Golder Associates Africa, 2022](#)). The project's objectives were to develop a sustainable agroecological-based village that generates decent jobs and income for the resettled beneficiaries and households, providing sustainable rural livelihoods. These objectives are framed within an economic and social development framework integrated with environmentally conscious solutions such as soil fertility, nutrition, green energy and water security. The aim is to develop a model that can be replicated in similar settings.

The following agricultural and related enterprises and supporting infrastructure have been set up at PAV:

- Vegetable and herb production in two multiplex tunnels, each covering 360 square meters.
- Household food gardens.
- A poultry project with infrastructure initially accommodating 1,500 layers. However, due to high mortality there were only 600 layers after 15 months.
- Biogas digester linked to a gas stove in an adjacent kitchen.
- Vermicast facility producing rich compost.
- Seedling propagating tunnel.
- A water system initiative, including boreholes, pumps, reservoir, several water tanks and roof water harvesting systems.
- Security cameras and fencing.
- A hall which was set up for general use by the community but has been used for agr1 training and other events related to the agri project (see [Figure 2](#)).

4 Methodology

A mixed research methodology was used to collect both quantitative data via a semi-structured questionnaire and qualitative data through focus group discussions and structured observations.



FIGURE 2
Phumlani Agri-village. Source: Authors own work. Location (25°45'33.6"S 29°58'01.4"E).

Combining quantitative and qualitative approaches improved the validity of the results and provided a more comprehensive understanding of the findings, as discussed by Smajic et al. (2022) and Sántha and Malomsoki-Sántha (2023), who explore the nuances of meaning, context, and participant experiences. These approaches refer to the mixed-methods research design that combines quantitative and qualitative approaches specifically, the use of semi-structured questionnaires (quantitative) and focus group discussions and structured qualitative observations in this study. When combined, these approaches complement each other, enabling triangulation of data and a more solid basis for drawing conclusions and offering recommendations. This integrated approach allows researchers to address various aspects of intricate phenomena, thereby enhancing the overall validity and reliability of study findings.

Using convenience sampling as part of quantitative research, 30 out of 32 Phumlani households' representatives and nine project beneficiaries completed respective questionnaires. This method allowed for the collection of data from participants who were readily available and willing to participate in the study, ensuring a high response rate and timely completion of the survey process. Despite the limitation of potential bias in sample selection, the approach provided valuable insights from the majority of the Phumlani households and the project beneficiaries. Convenience sampling inherently introduces bias, as it relies on the availability and willingness of participants rather than a randomized selection process. This can lead to overrepresentation of certain groups while excluding others, potentially skewing the findings. Although the study captures insights from a majority of Phumlani households and project beneficiaries, the lack of randomization limits the ability to generalize the results to the entire community or similar contexts.

The impact of the PAV agroecological model was analysed using a Sustainable Livelihood Assets (SLA) framework, focusing on its social, physical and economic impacts (Figure 3). The SLA framework together with the Sustainable Development Goals (SDGs) indices were used to better understand and benchmark the main factors and contribution of the project to the livelihoods of people in marginalized

communities (Li et al., 2020). Social parameters included community engagement, knowledge sharing, and perceived well-being, while physical parameters covered infrastructure, access to natural resources, and agricultural productivity. Economic parameters encompassed household income, employment opportunities, and financial security (Fahad et al., 2023). By combining these two frameworks, the analysis can become more robust and actionable. It provides policymakers, researchers, and practitioners with a nuanced understanding that can inform more balanced and effective strategies for promoting well-being and sustainability. This comprehensive perspective can lead to more targeted interventions, better resource allocation, and ultimately, a more sustainable and equitable future. This approach helps identify the strengths and vulnerabilities of communities, guiding interventions to enhance resilience and reduce poverty.

Quantitative data collected through semi-structured questionnaires were analysed using SPSS (Statistical Package for the Social Sciences), employing descriptive statistics such as means, frequencies, and percentages to summarize responses. For the qualitative research component, data collected through focus group discussions and structured observations were probed using thematic analysis to identify key patterns, meanings, and recurring themes. Responses from participants were transcribed and coded systematically, allowing for the categorization of emerging themes related to social, physical, and economic impacts. Manual coding techniques were used to organize data and identify linkages between different concepts. Thematic analysis provided a deeper understanding of participant experiences, contextual factors, and the nuances of the PAV agroecological model's impact.

The key difference between qualitative research and quantitative research lies in their focus, quantitative research provided measurable, generalizable findings, while qualitative research captured in-depth participant experiences. By integrating both methods, the study ensured triangulation of data, enhancing the validity and reliability of findings while offering a more nuanced understanding of the project's overall impact.

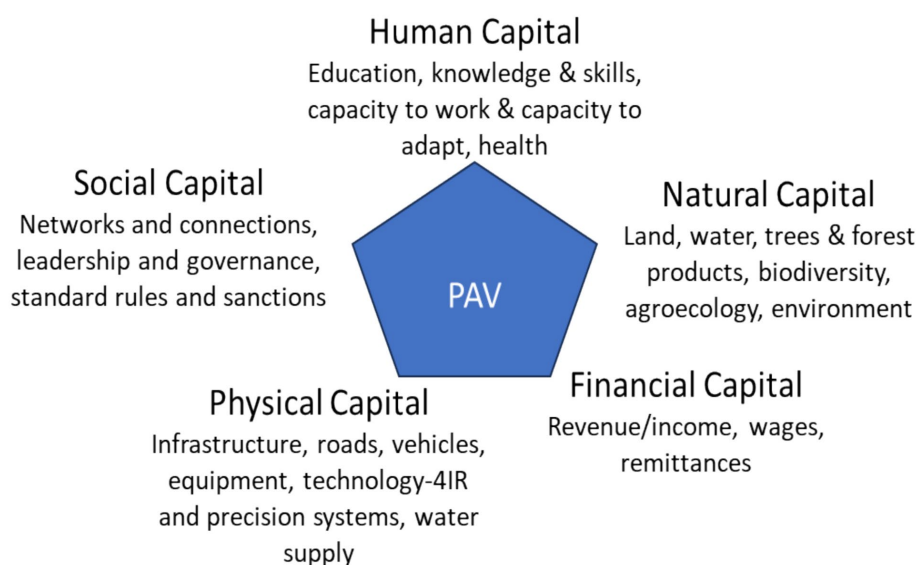


FIGURE 3
Sustainable livelihood assets framework. Source: (Scoones, 1998).

TABLE 1 The SLA and SDG linkages to project outcomes with a timeline.

SLA component	SDG linkage	Project outcome	Timeline
Skills development.	Quality education (SDG 4).	Enhanced skills in farming.	Ongoing
Income generation.	No poverty (SDG 1) and zero hunger (SDG 2).	Increased income through vegetable sales	Ongoing
Environmental stewardship.	Clean water and Sanitation (SDG 6).	Improved water security and soil health.	Ongoing
Gender mainstreaming.	Reduced inequalities (SDG 10)	Increased participation by women.	Ongoing
Community health and development.	Sustainable cities and communities (SDG 11).	Strengthened social capital and cohesion	Ongoing
Jobs creation.	No poverty (SDG 1).	Created thirty new jobs, with ten of them being permanent positions.	Ongoing

The decentralized governance structure in the project was developed collaboratively by project stakeholders, including community representatives, project coordinators, and local governance bodies, to ensure inclusivity and shared decision-making. This structure allows beneficiaries to actively participate in shaping project rules and policies, reinforcing a sense of ownership and accountability. Oversight and enforcement of these governance mechanisms were carried out by a combination of elected beneficiary representatives, project facilitators, and advisory committees who monitor adherence to agreed-upon guidelines and mediate conflicts when necessary. By embedding participatory governance, the project not only strengthens social cohesion but also fosters sustainability through locally driven leadership.

4.1 United Nations Sustainable Development Goals (SDGs)

Fuso Nerini et al. (2019) state that the SDGs aim to transform our world. They represent a call to action to eradicate poverty and

inequality, protect the planet, and ensure universal access to health, justice, and prosperity. PAV is emerging as a living, dynamic economic development laboratory illustrating that new communities can be established and modelled to create economic opportunities through strategic investment, capacity building, infrastructure development, and the utilization of available and sustainable resources. The PAV project aligns with and addresses many of the 17 SDG goals.

Table 1 illustrates the linkages between Sustainable Livelihood Approaches (SLA) and Sustainable Development Goals (SDGs) as they relate to project outcomes, emphasizing a structured timeline for interventions. The table highlights key components such as skills development in farming skills, which align with the goal of providing decent jobs and quality education (SDG 4). Additionally, it addresses income generation through the sale of vegetables, supported by necessary infrastructure like veggie tunnels and water systems, which directly contributes to the goals of No Poverty (SDG 1) and Zero Hunger (SDG 2). Furthermore, the focus on environmental stewardship, including water security and soil conservation, is crucial for achieving clean water and sanitation (SDG 6) and promoting sustainable communities.

5 Results and discussions

The study's findings are delineated within the parameters of the SLA and SDG frameworks. These two frameworks serve as blueprints for benchmarking and standardizing results and impacts across similar projects.

5.1 Impact measurement using SLA and SDGs

5.1.1 Financial/economic capital and SDG 1 and 8: no poverty and decent work and economic growth

5.1.1.1 Major sources of income

The project created thirty new jobs, with ten of them being permanent positions. Seventy per cent of the beneficiaries reported that the income from the project was a significant source of their household income and contributed to the welfare of other members of the household. The PAV project has contributed to reducing poverty and established a small but reasonable income source for previously unemployed persons, thereby contributing to SDGs 1 and 8 and improving their financial capital.

Mathebula et al. (2017) and Chen et al. (2022) studies in traditional settlements showed that the primary income sources were remittances, business, and labor income. In rural areas, social transfers and labor income were the highest sources of income at 4.24 and 2.8%, respectively. This indicate that income sources are highly fragmented or that other sources, such as remittances, subsistence farming, or informal business activities, contribute significantly but were not categorized as primary income sources in the study. Thus, PAV's contribution to household income was noteworthy, clearly showing the importance of self-reliance. This underscores the significant role this income stream plays in sustaining rural households. The reliance on diverse income sources not only highlights resilience but also emphasizes the importance of fostering self-reliance strategies within rural communities and the need to influence policies and initiatives that promote self-reliance strategies within rural communities. Encouraging such strategies can lead to greater economic stability and sustainability, ensuring that rural households can thrive even in the face of adversity. By fostering skills development, entrepreneurship, and access to resources, rural communities can build a more robust and adaptable economic foundation.

5.1.2 Contribution to human capital and SDG 2 and 3

5.1.2.1 Household food security and access to a wide range of nutritious food

The project promoted better household food security (SDG 2) through improved dietary diversity and good health and well-being (SDG 3). These contributions improve human capital through improved health and the ability to work actively. All beneficiaries expressed that the project positively influenced their household food security by providing a consistent and wide range of vegetables, herbs, and eggs. The beneficiaries also reported improved general health and well-being.

An article by Mtsintsilana (2023) published in *The Conversation*, showed high levels of social vulnerability in the country linked to food insecurity. Furthermore, over 20.6% of South Africans were reported as socially vulnerable, and 20.4% were food insecure, equating to about 7.8 million people from a sample of 39.6 million people. Vandevijvere et al. (2019) stated that having access to different food types which were readily available for consumption and bodily health is referred to as having a "wide range of food." A healthy body needs various nutrients, including vitamins, minerals, fibre, proteins, carbohydrates, and fats, which can be found in various dietary forms. The agroecological set-up at PAV allows the beneficiaries to access a range of organic food, thus improving dietary diversity. According to Oldewage-Theron and Egal (2021) and Rudolph et al. (2021), many South African households experience food and nutrition insecurity. Projects such as PAV clearly demonstrated some practical solutions to address household food and nutrition insecurity. There is a need for policies that integrate agroecological approaches into national food security and nutrition strategies, ensuring alignment with broader goals such as poverty reduction, environmental sustainability, and climate resilience. This approach promotes sustainable farming practices that enhance biodiversity, conserve resources, and support ecological balance. By aligning these policies with broader goals such as poverty reduction, they can create economic opportunities for smallholder farmers and rural communities. Additionally, integrating environmental sustainability helps protect natural resources and ecosystems, contributing to long-term agricultural productivity. Climate resilience is another key aspect, as agroecological practices can mitigate the impacts of climate change by enhancing soil health and water management. Together, these integrated policies can create a holistic framework for achieving sustainable development and food security.

5.1.3 Human capital and SDG 4 quality education

5.1.3.1 Training and skills development Programme

Almost all beneficiaries reported increased knowledge in agriculture and a basic and better understanding in agribusiness, management, and financial record keeping skills. Lembani et al. (2020) showed that developing the knowledge and skills of project beneficiaries is critical in improving their quality of life, job prospects, and productivity.

Human capital in skills and capacity development is essential for the project's overall sustainability. Funding for the project was provided by corporate partners, specifically a mining company and a construction company. Although government provides some support, the benefits would be more widespread with increased funding and more efficient extension services thus improving overall societal well-being. However, the challenge remains that such public funding is either unavailable or severely limited. Nevertheless, projects like this demonstrate viable models for implementation, ensuring that when funds do become available, there is already a proven model which could be scaled. Addressing SDG 4 ensures inclusive and equitable quality education and promotes lifelong learning opportunities for all. The project's skills development meets essential requirements and integrated important practical application. A major component of the agroecological design at PAV is an integrated skills and capacity-building programme, including national AgriSETA-accredited courses. These courses have been offered in both contact and online

formats by experienced trainers and facilitators with a qualified moderator to ensure standardization and competence. The offerings have also developed relevant technical and important skills such as communication, customer relations, and marketing, for the project beneficiaries. There is a need to partner with local community organizations, cooperatives, and agricultural extension services to promote awareness of online courses and facilitate enrolment among rural participants. Collaborating closely with local partners enables the customization of course content to effectively tackle the unique agricultural challenges and requirements that are prominent in the region. This tailored approach significantly boosts the courses' relevance and practicality.

5.1.4 Social capital and SDG 5 and 17: gender equality and networking

Social Capital is essential to Sustainable Livelihood Assets (SLA). Networks of relationships among people who live and work in a particular society enable that society to function effectively (Rodgers et al., 2019). Almost 60% of the beneficiaries reported improved social cohesion, decreased gender discrimination, and improved stakeholder networking, including improved working relationships with the local municipality, suppliers, and markets. In community projects like PAV, social cohesion and capital are essential factors contributing towards the project's sustainability.

These factors including community-building skills, participation, and the active mobilization of village members, are vital. Community food gardens may be more about community than they are about gardening. The agri-enterprises offer safe spaces where people can collectively gather, network, and identify challenges and solutions as village residents (Kingsley and Townsend, 2006). Glover (2004) found that a community food garden could be both a consequence and a source of social capital. Consequently, PAV has been a product of a persistent network of individuals committed to its development. As a source of social capital, it has strengthened social ties, facilitated further connections among neighbors, and encouraged residents to watch out for one another. The PAV project has secured land and water with assistance from Exxaro Mining. Training facilitated by Siyakhana Growth and Development NPO draws upon the local participation of beneficiaries, households, and the Community Property Association (CPA), an organization responsible for managing all aspects of the village and to encourage and facilitate community coherence and social capital (Wills et al., 2010). This collaborative approach not only facilitated a platform for sustainable development but also strengthened community bonds and organizational effectiveness within the village setting. In addition, these collaborative efforts typically engaged with numerous organizations and stakeholders, each bringing their unique strengths and expertise. This collective approach improves organizational effectiveness by integrating complementary resources and capabilities.

5.1.5 SDG 11 sustainable cities and communities

5.1.5.1 Governance structure

Sustainable villages are becoming increasingly important due to the need for environmentally friendly and socially responsible living spaces. These village's aim is to minimize their environmental impact by incorporating sustainable practices in their development and operation. The development of sustainable villages is becoming a

global focus, as they offer a solution to the problems of rural–urban migration and unsustainable living practices (Adesipo et al., 2020). By incorporating sustainable principles into their design and operation, villages can provide a glimpse of a future where communities are more environmentally friendly and socially responsible.

The PAV project improved both the human settlement planning and governance structure. The beneficiaries reported satisfaction with the new governance structure, which is a decentralized governance system that is applied where collective decision-making with the beneficiaries adds much value to the project's mission. Lee-Geiller et al. (2022) explain that the governance structure refers to the project management framework, especially regarding rules, procedures, roles and the division of responsibilities within the whole decision-making process components applied at PAV (UCT SDGs, 2023). Kroll and Adelle (2022) assert that working at the intersection of research, policy advocacy and public discourse, themes such as urban food systems, resilience, infrastructure, health, and informality provide lenses to investigate the conditions necessary for sustainable urban development. The authors argue that these principles apply equally to rural development in Africa. While the SDGs are a global agenda and national imperative, their effective implementation and action are crucial at the city level. Harnessing co-production, embedded research and comparative research are essential for successful implementation. Co-production entails partnering with stakeholders, such as community members and smallholder farmers, to design and execute projects. This collaboration cultivates ownership and trust, ensuring that solutions effectively address community needs. By integrating local knowledge and perspectives, co-production enhances the pertinence and longevity of interventions.

5.1.6 Physical capital and SDG 6 and 7: clean water and sanitation, affordable and clean energy and green infrastructure

The Sustainable Development Goals (SDGs) of Clean Water and Sanitation, Affordable and Clean Energy, and Green Infrastructure all relate to the development of sustainable villages. Clean water and sanitation are crucial for the health and wellbeing of communities, and sustainable villages can incorporate water-saving technologies and recycling systems to reduce water usage. Affordable and clean energy is another key goal, and sustainable villages can use renewable energy sources such as solar and wind power to meet their energy needs. Green infrastructure, such as parks, gardens, and green spaces, can help to create sustainable villages that are liveable and provide a sense of connection to nature. Several green infrastructures have been built or installed at PAV. Monteiro et al. (2020) define green infrastructure as “a strategically planned infrastructure that is designed and managed to deliver a wide range of ecosystem services, such as improving water quality and waste management using biogas digestors.” At PAV, revamping the water system by refurbishing and drilling new boreholes was done to ensure adequate and sustainable water for the agri projects and households. The Africa Regional Forum-Water Dialogue recognized that both surface and groundwater remain key to the sustainable development of the African continent.

The water demand in Africa is increasing due to population growth, socio-economic development, and large-scale agriculture requirements (Global Water Partnership Southern Africa, 2021). Other green and circular infrastructure includes a functioning biogas digester using biomass such as dung for producing biogas (energy) and

bio-slurry as fertilizer (Arshad et al., 2022). In addition, a wormery uses food and garden waste, producing rich worm tea and compost (De la Vega, 2016), while hemp plants, a new cultivar which has been planted at the agri project will contribute to phytoremediation and soil rehabilitation (Hlihoh et al., 2022). Biogas digestors generate energy and produce bio-slurry for fertilizing crops, while wormeries effectively convert food and garden waste into valuable resources. Hemp plants are versatile, playing a crucial role in phytoremediation and enhancing soil quality. These approaches underscore sustainable solutions that can greatly benefit environmental and agricultural sustainability.

The provision of green infrastructure, including the refurbishment of the water system and the drilling of new boreholes at PAV, was indeed a necessary precondition for the project rather than an outcome of agroecological transformation itself. While infrastructure, training, and inputs significantly enhance agricultural productivity in any context, the key contribution of agroecology lies in fostering self-sufficiency and reducing reliance on external inputs over time. This study highlights that even in the absence of ongoing infrastructural support, agroecology equips communities with the knowledge and techniques to sustain food production, improve soil health, and diversify their diets, ultimately contributing to long-term resilience. Additionally, the transition to agroecology brings health benefits by reducing exposure to agro-toxins and encouraging more diverse and nutritious food consumption. These findings support the argument that government investment in agroecological initiatives rather than subsidies for synthetic fertilizers and pesticides can yield more sustainable and equitable outcomes for subsistence farming communities.

5.1.7 SDG 17: partnerships, collaboration, and community participation

Groot and Abma (2019) state that collaboration is an effective way for community projects to increase their impact and sustainability. Different stakeholders contribute to various interventions and support systems essential for the project's continuity and success. Several partnerships and collaborations were established. The major funding partner is Exxaro Mining Company, with additional support from Komatsu Construction, an earthmoving and utility equipment company. Siyakhana Growth and Development NPO is the implementing agent, with extensive experience and expertise in project implementation and management. The Centre for Ecological Intelligence at the University of Johannesburg is the research and institutional partner. The Mpumalanga Department of Agriculture, Mpumalanga University, and Agri Seta collaborate in the project. A key alliance is the CPA whose task is to enable active community participation and buy-in, and which must play an increasing role in the project's governance. Successful partnerships, collaboration, and community participation rely on transparent communication, mutual trust, common objectives, and a dedication to fairness and inclusivity. These factors contribute to the development of social capital and the establishment of resilient communities that can effectively tackle a variety of issues.

5.2 Conclusion and recommendations

The application of the agroecological framework proved to be transformative for community development over a

twenty-four-month period. Agroecology, a holistic and integrated approach, applied ecological and social concepts and principles to the design and management of projects. The application of these fundamental building blocks confirmed the applicability and relevance of agroecology. Although PAV has huge potential for upscaling, additional infrastructure. Entrepreneurial and enterprise interventions and internal project management are essential for its sustainability.

Recommendations for further interventions include:

- 1 Strengthening existing partnerships and fostering collaborations to enhance the impact and reach of the project.
- 2 Incorporating Fourth Industrial Revolution (4IR) technologies and precision agriculture systems to optimize efficiency and productivity.
- 3 Investing in ongoing training and research initiatives to stay abreast of the latest developments and innovations in agroecology, water energy and food nexus.
- 4 Ensuring that training especially in entrepreneurship and small business management, and leadership development programmes are tailored to the specific needs and opportunities for women and youth involvement but also including older persons.
- 5 Strengthen social capital and cohesion.

Corporations and government are urged to play a crucial role by developing policies and support programmes to promote the adoption of an agroecological framework in similar settings in South Africa. This will contribute to the broader sustainability and success of initiatives like Phumulani Agri-village.

There is a lack of standardized methodologies and metrics for evaluating the diverse outcomes of agroecological farming, which further complicates the comparison and synthesis of research findings. Addressing these gaps requires a concerted effort to conduct longitudinal research and develop comprehensive evaluation frameworks that can capture the multifaceted benefits of agroecology. This will provide a more accurate and holistic understanding of its potential to address global challenges such as food security.

The implementation of the agroecological framework in Phumulani Agri-village (PAV) demonstrated significant transformative potential, yet challenges remain in ensuring long-term sustainability and scalability. Key hurdles included the need for additional infrastructure, stronger internal project management, and sustained entrepreneurial support. While the agroecological approach fostered resilience, social cohesion, and environmental benefits, the absence of standardized methodologies for evaluating outcomes limits broader applicability. Future interventions should focus on refining evaluation frameworks, integrating innovative technologies, and strengthening multi-stakeholder collaborations. Additionally, ensuring long-term financial and policy support will be critical for replicating this model in other contexts, furthering its role in addressing food security and climate resilience in South Africa and beyond.

The Phumulani Agri-village model aligns with other agroecological projects in Southern Africa, such as Zimbabwe's Shashe Agroecology School and Zambia's Participatory Ecological Land Use Management (PELUM) initiatives, which emphasize farmer-led innovations and sustainability. However, PAV uniquely integrates a structured entrepreneurial component alongside agroecology, making it a potential

blueprint for fostering both ecological resilience and economic viability in similar contexts. Expanding these principles across the region could significantly enhance sustainable food production and rural livelihoods.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by University of Johannesburg Research Ethics Committee (UJ REC). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

MR: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. MZ: Conceptualization, Methodology, Writing – original draft.

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References

- Adesipo, A., Fadeyi, O., Kuca, K., Krejcar, O., Selamat, A., and Adenola, M. (2020). Smart and climate-smart agricultural trends as core aspects of smart village functions. *Sensors* 20:5977. doi: 10.3390/s20215977
- Amoah, L. N. A., and Simatele, M. D. (2021). Food security and coping strategies of rural household livelihoods to climate change in the eastern cape of South Africa. *Front. Sustain. Food Syst.* 5:692185. doi: 10.3389/fsufs.2021.692185
- Anderson, C., Bruil, J., Chappell, M. J., Kiss, C., and Pimbert, M. (2019). From transition to domains of transformation: getting to sustainable and just food systems through agroecology. *Sustain. For.* 11:5272. doi: 10.3390/su11195272
- Arshad, M., Ansari, A. R., Qadir, R., Tahir, M. H., Nadeem, A., Mehmood, T., et al. (2022). Green electricity generation from biogas of cattle manure: an assessment of potential and feasibility in Pakistan. *Front. Energy Res.* 10:911485. doi: 10.3389/fenrg.2022.911485
- Barrios, E., Gemmill-Herren, B., Bicksler, A., Siliprandi, E., Brathwaite, R., Moller, S., et al. (2020). The 10 elements of Agroecology: enabling transitions towards sustainable agriculture and food systems through visual narratives. *Ecosyst. People* 16, 230–247. doi: 10.1080/26395916.2020.1808705
- Burchi, F., and De Muro, P. (2015). From food availability to nutritional capabilities: advancing food security analysis. *Food Policy* 60, 10–19. doi: 10.1016/j.foodpol.2015.03.008
- Chen, L., Chen, X., Hongxin, W., Zhu, L., and Lang, L. (2022). Research on spatial and dynamic planning methods for settlement buildings based on data mining. *Discret. Dyn. Nat. Soc.* 2022, 1–11. doi: 10.1155/2022/3528605
- Dagoudo, B. A., Ssekewya, C., Tovignan, S., Ssekandi, J., and Nina, P. M. (2023). Agroecological business model: a pillar stone for women's entrepreneurship in agroecology and sustainable food systems. *Int. J. Curr. Sci. Res. Rev.* 6:31. doi: 10.47191/ijcsrr/v6-i1-31
- De la Vega, A. (2016). "Vermicomposting: the future of sustainable agriculture and organic waste management" in Lessons from the USA and Cuba. Winston Churchill Memorial Trust Fellow, 1–48.
- Dlamini, S. N., Craig, A., Mtintsilana, A., Mapanga, W., Toit, J. D., Ware, L. J., et al. (2023). Food insecurity and coping strategies and their association with anxiety and depression: a nationally representative south african survey. *Public Health Nutr.* 26, 705–715. doi: 10.1017/s1368980023000186
- Dushyant, Sharma, K., Roy, S., Rooma, K., Mahan, N., and Kumar, P. (2024). Principles and applications of agroecology: a review. *J. Sci. Res. Rep.* 30, 843–853. doi: 10.9734/jsrr/2024/v30i52002
- Fahad, S., Nguyen-Thi-Lan, H., Nguyen-Manh, D., and Tran-Duc, H. (2023). Analyzing the status of multidimensional poverty of rural households by using sustainable livelihood framework: policy implications for economic growth. *Environ. Sci. Pollut. Res.* 30, 16106–16119. doi: 10.1007/s11356-022-23143-0
- Falconnier, G. N., Cardinael, R., Corbeels, M., Baudron, F., Chivenge, P., Couédel, A., et al. (2023). The input reduction principle of agroecology is wrong when it comes to mineral fertilizer use in Sub-Saharan Africa. *Outlook Agric.* 52, 311–326. doi: 10.1177/00307270231199795
- FAO. Agroecology knowledge hub. Food and agriculture organization of the united nations. (2018). Available online at: <http://www.fao.org/agroecology/overview/en> (Accessed 23 March 2024).
- Fuso Nerini, F., Sovacool, B., Hughes, N., Cozzi, L., Cosgrave, E., Howells, M., et al. (2019). Connecting climate action with other sustainable development goals. *Nat. Sustain.* 2, 674–680. doi: 10.1038/s41893-019-0334-y
- Global Water Partnership Southern Africa (2021). Call to action: Accelerating action on SDG 6 implementation in Africa. Available online at: <https://www.gwp.org/en/GWP-SouthernAfrica/About-GWP-SAF/more/News/call-to-action-accelerating-action-on-sdg-6-implementation-in-africa/> (Accessed May 31, 2021).
- Glover, T. D. (2004). Social capital in the lived experiences of community gardeners. *Leis. Sci.* 26, 143–162. doi: 10.1080/01490400490432064
- Golder Associates Africa (2022). Social impact assessment for the Dalmanutha wind energy facilities. Mpumalanga: Belfast.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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- Govender, L., Pillay, K., Siwela, M., Modi, A., and Mabhaudhi, T. (2017). Food and nutrition insecurity in selected rural communities of KwaZulu-Natal, South Africa—linking human nutrition and agriculture. *Int. J. Environ. Res. Public Health* 14:17. doi: 10.3390/ijerph14010017
- Groot, B., and Abma, T. (2019). Partnership, collaboration and power ethics in participatory research for health and social wellbeing: cases and commentaries. Oxon: Routledge.
- Hlihor, R. M., Petronela, C., and Gavrilescu, M. (2022). Removal of heavy metals from the environment by phytoremediation and microbial remediation. *Sustain. Solut. Environ. Pollut.* 5, 95–146. doi: 10.1002/9781119827665.ch2
- James, D., Wolff, R., and Wittman, H. (2023). Agroecology as a philosophy of life. *Agric. Hum. Values* 40, 1437–1450. doi: 10.1007/s10460-023-10455-1
- Kingsley, J., and Townsend, M. (2006). 'Dig in' to social capital: community gardens as mechanisms for growing urban social connectedness. *Urban Policy Res.* 24, 525–537. doi: 10.1080/08111140601035200
- Kroll, F., and Adelle, C. (2022). Lockdown, resilience and emergency statecraft in the Cape Town food system. *Cities* 131:104004. doi: 10.1016/j.cities.2022.104004
- Lee-Geiller, P., de Lauwere, C., and Edwards, D. (2022). The Political impact of the sustainable development goals. *Cambridge University Press*. doi: 10.1017/9781009082945
- Lekganyane, G. (2024). The South African social policy and the role of green social work: COVID-19 and beyond. *Social Work*. doi: 10.5772/intechopen.1004121
- Lembani, R., Gunter, A., Breines, M., and Dalu, M. T. B. (2020). The same course, different access: the digital divide between urban and rural distance education students in South Africa. *J. Geogr. High. Educ.* 44, 70–84. doi: 10.1080/03098265.2019.1694876
- Li, W., Shuai, C., Shuai, Y., Cheng, X., Liu, Y., and Huang, F. (2020). How livelihood assets contribute to sustainable development of smallholder farmers. *J. Int. Dev.* 32, 408–429. doi: 10.1002/jid.3461
- Mabhaudhi, T., Chibarabada, T. P., Chimonyo, V. G. P., Murugani, V. G., Pereira, L. M., Sobratee, N., et al. (2018). Mainstreaming underutilised indigenous and traditional crops into food systems: a south African perspective. *Sustain. For.* 11:172. doi: 10.3390/su11010172
- Masipa, T. (2017). The impact of climate change on food security in South Africa: current realities and challenges ahead. *Jamba* 9, 1–7. doi: 10.4102/jamba.v9i1.411
- Mathebula, J., Molokomme, M., Jonas, S., and Nhemachena, C. (2017). Estimating household income diversification in South Africa: a case study of three provinces. *S. Afr. J. Sci.* 113, 1–9. doi: 10.17159/sajs.2017/20160073
- Mbhenyane, X. G., and Tambe, A. B. (2024). The influence of household and community food environments on food insecurity in Limpopo province, South Africa. *Int. J. Environ. Res. Public Health* 21:125. doi: 10.3390/ijerph21020125
- Monteiro, R., Ferreira, J. C., and Antunes, P. (2020). Green infrastructure planning principles: an integrated literature review. *Land* 9:525. doi: 10.3390/land9120525
- Mthembu, A., and Hlophe, S. (2021). Building resilience to climate change in vulnerable communities: a case study of Umkhanyakude district municipality. *Town Regl. Plan.* 77, 42–56. doi: 10.18820/2415-0495/trp77i1.4
- Mtintsilana, A., Dlamini, S. N., Mapanga, W., Craig, A., Toit, J. D., Ware, L. J., et al. (2022). Social vulnerability and its association with food insecurity in the south african population: findings from a national survey. *J. Public Health Policy* 43, 575–592. doi: 10.1057/s41271-022-00370-w
- Mtintsilana, A. (2023). Hunger in South Africa: study shows one in five are at risk. The conversation. Available online at: <https://theconversation.com/hunger-in-south-africa-study-shows-one-in-five-are-at-risk-199133> (Accessed February 15, 2023).
- Napier, C., Oldewage-Theron, W., and Makhaye, B. (2018). Predictors of food insecurity and coping strategies of women asylum seekers and refugees in durban, South Africa. *Agriculture & amp. Food Secur.* 7:67. doi: 10.1186/s40066-018-0220-2
- Ncisana, L., Ntuli, V. A., Sibisi, N. T., Masha, M. F., Mboweni, M. S., Satekge, M. A., et al. (2023). A comparative study of teaching approaches in agro-ecology: an investigation of 10th-grade agricultural sciences learners in selected schools. *Sustain. For.* 15:4048. doi: 10.3390/su15054048
- Ngumbela, K., Mothiba, T., and Van der Merwe, P. (2020). "Contextualizing project evaluation: The role of stakeholder perspectives." *Int. J. Dev. Stud.* 12, 245–262.
- Novaes, T. H. (2024). "Green revolution", Agroecology and the MST Agroecology schools" in Associated labor and production in the age of barbarism: Education beyond capital. ed. H. T. Novaes (Springer Nature Switzerland: Cham), 167–182.
- Nyiwul, L. (2021). Climate change adaptation and inequality in Africa: case of water, energy and food insecurity. *J. Clean. Prod.* 278:123393. doi: 10.1016/j.jclepro.2020.123393
- Oldewage-Theron, W., and Egal, A. A. (2021). Is food insecurity a problem among the elderly in Sharpeville, South Africa? *Food Secur.* 13, 71–81. doi: 10.1007/s12571-020-01125-9
- Owoputi, I., Booth, N., Luginaah, I., Nyantakyi-Frimpong, H., Shumba, L., Dakishoni, L., et al. (2022). Does crop diversity influence household food security and women's individual dietary diversity? A cross-sectional study of malawian farmers in a participatory agroecology and nutrition project. *Food Nutr. Bull.* 43, 395–411. doi: 10.1177/03795721221126787
- Patrick, H. O., Khalema, E., Abiolu, O. A., Jiatuyi, E. J., and Patrick, R. T. I. (2021). South africa's multiple vulnerabilities, food security and livelihood options in the covid-19 new order: an annotation. *J. Transdiscip. Res. South. Africa* 17:1037. doi: 10.4102/td.v17i1.1037
- Rodgers, J., Valuev, A. V., Hswen, Y., and Subramanian, S. V. (2019). Social capital and physical health: an updated review of the literature for 2007–2018. *Soc. Sci. Med.* 236:112360. doi: 10.1016/j.socscimed.2019.112360
- Rudolph, M., Mello, A., and Muchesa, E. (2021). Food security in urban cities: a case study conducted in Johannesburg, South Africa, *J. Food Secur.* 9, 46–55. doi: 10.12691/jfs-9-2-2
- Sands, B., Machado, M. R., White, A., Zent, E., and Gould, R. (2023). Moving towards an anti-colonial definition for regenerative agriculture. *Agric. Hum. Values* 40, 1697–1716. doi: 10.1007/s10460-023-10429-3
- Sántha, K., and Malomsoki-Sántha, Á. (2023). Methodological aspects for applied linguistic research – mixed methods, triangulation. *Acta Univ. Sapientiae Philol.* 15, 1–13. doi: 10.2478/ausp-2023-0013
- Schwarz, R., Birkman, J., and Kienberger, S. (2020). The relationship between energy access and food security in South Africa: A socio-economic perspective. *Energy Policy*, 143:111546. doi: 10.1016/j.enpol.2020.111546
- Scoones, I. (1998). Sustainable rural livelihoods: A framework for analysis. IDS Working paper no 72., Sussex, UK: Institute of development studies.
- Siegner, A. B., Acey, C., and Sowerwine, J. (2019). Producing urban agroecology in the east bay: from soil health to community empowerment. *Agroecol. Sustain. Food Syst.* 44, 566–593. doi: 10.1080/21683565.2019.1690615
- Smajic, E., Avdić, D., Pasic, A., Pric, A., and Stancic, M. (2022). Mixed methodology of scientific research in healthcare. *Acta Inform. Med.* 30, 57–60. doi: 10.5455/aim.2022.30.57-60
- Stahacz, C., Alwan, N. A., Taylor, E., Smith, D., and Ziauddeen, N. (2024). The impact of food aid interventions on food insecurity, diet quality and mental health in households with children in high-income countries: a systematic review. *Public Health Nutr.* 27:e195. doi: 10.1017/S1368980024001769
- Tataridas, A., Travlos, I., and Freitas, H. (2023). Agroecology and invasive alien plants: a winner-take-all game. *Front. Plant Sci.* 14. doi: 10.3389/fpls.2023.1143814
- Thomas, L. S., Buch, É., and Pillay, Y. (2021). An analysis of the services provided by community health workers within an urban district in South Africa: a key contribution towards universal access to care. *Hum. Resour. Health* 19:22. doi: 10.1186/s12960-021-00565-4
- Toit, A. D., Mac Donald, R., Steyn, E., Mahlanza, Z. P., Zulu, A. B., and Wit, M. d. (2023). Review of the underutilized indigenous *Portulacaria afra* (spekboom) as a sustainable edible food source. *Agronomy* 13:1206. doi: 10.3390/agronomy13051206
- UCT SDGs (2023). UCT and the Sustainable Development Goals Report 2023. Available online at: https://uct.ac.za/sites/default/files/media/documents/uct_ac_za/39/sdg-report-2023.pdf (Accessed May 4, 2025).
- Vandevijvere, S., Barquera, S., Caceres, G., Corvalan, C., Karupaiah, T., Kroker-Lobos, M. F., et al. (2019). An 11-country study to benchmark the implementation of recommended nutrition policies by national governments using the healthy food environment policy index, 2015–2018. *Obes. Rev.* 20, 57–66. doi: 10.1111/obr.12819
- Vyas-Doorgapersad, S., Shava, E., and Olowu, A. (2023). Food security and nutrition governance post-covid-19 in africa. *Insights Into Regl. Dev.* 5, 58–72. doi: 10.9770/ird.2023.5.3(4)
- Wang, J. (2022). Drivers of the sustainable development of agro-industrial parks: evidence from Jiangsu province, China. *SAGE Open* 12:215824402211444. doi: 10.1177/21582440221144415
- Ware, L. J., Kim, A. W., Pioreschi, A., Nyati, L. H., Taljaard, W., Draper, C. E., et al. (2021). Social vulnerability, parity and food insecurity in urban south african young women: the healthy life trajectories initiative (helti) study. *J. Public Health Policy* 42, 373–389. doi: 10.1057/s41271-021-00289-8
- Wegerif, M. (2021). The impact of covid-19 on black farmers in South Africa. *Agrekon* 61, 52–66. doi: 10.1080/03031853.2021.1971097
- Wezel, A., Herren, B., Kerr, R. B., Barrios, E., Gonçalves, A. L., and Sinclair, F. (2020). Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. *Agron. Sustain. Dev.* 40:646. doi: 10.1007/s13593-020-00646-z
- Wills, J., Chinemana, F., and Rudolph, M. (2010). Growing or connecting? An urban food garden in Johannesburg. *Health Promot. Int.* 25, 33–41. doi: 10.1093/heapro/dap042
- Zenda, M., Rudolph, M., and Harley, C. (2024). The impact of climate variability on the livelihoods of smallholder farmers in an agricultural village in the wider Belfast area, Mpumalanga Province, South Africa. *Atmosphere*, 15:1353. doi: 10.3390/atmos15111353