

CHAPTER 11

Aquaponic Systems for Small-Scale Farming in Africa: Potential and Challenges

Bernd Ueberschär, Christian Henning,
and Johannes Ziesmer

Introduction

The global population has grown exponentially over the past century, resulting in a significant increase in food demand. According to projections by the United Nations (UN), the world's population is expected to reach 9.7 billion by the year 2050 (United Nations 2019). Meeting the nutritional needs of nearly 10 billion people will require the development of food systems that are innovative, sustainable, and equitable. According to estimates from the Food and Agriculture Organization (FAO 2017), these food system transformations are necessary to meet the growing global demand for food. However, attainment of these transformations is hindered by several challenges, including climate change, land degradation, resource scarcity, and pollution (Goddek et al. 2019). Despite advancements in crop breeding and intensified agricultural production methods, current trends indicate that food production will not meet future demand (Bajželj et al. 2014).

Africa, in particular, is significantly affected by these challenges. According to Zhang and Cai (2011), by the end of the 21st century, climate change could have reduced the continent's arable land by up to 18 percent. Over 20 percent of Africans – approximately 257 million people – are undernourished due to the interaction of various dynamics, including conflicts, economic instability, and the lingering repercussions of the COVID-19 pandemic (FAO 2023). Conventional agricultural expansion is increasingly constrained by competition for land with other sectors and by declining water availability, especially in arid and semi-arid regions.

In this context, there is an urgent need for innovative and resource-efficient farming technologies. Integrated agriculture-aquaculture (IAA) systems are one such promising approach. These systems are particularly relevant for developing countries, where the farming community has limited capacity for intensive, fed aquaculture (Birhanu and Natarajan 2019). By integrating aquaculture with crop or livestock farming, IAA systems effectively recycle waste streams, minimize input requirements, and enhance synergies across farm enterprises (Singh et al. 1991). Typically operated as family farming systems, they contribute to food, income, and employment generation while also minimizing the impacts of environmental externalities.

Aquaponics is a specialized form of IAA that integrates fish farming (aquaculture) with soil-less plant cultivation (hydroponics). This closed-loop system

enhances water-use efficiency, reduces dependence on chemical fertilizers, and enables high-yield food production in settings with limited resources. Research indicates that aquaponics has the potential to enhance rural livelihoods, offer cost-effective protein sources, and optimize the use of limited land and water resources. For instance, a South African study demonstrated that small-scale aquaponic systems can be economically viable when optimized plant-to-fish ratios are applied (Babatunde et al. 2021).

Beyond local benefits, aquaponics is increasingly recognized as a frontier agricultural technology. A World Bank report highlights its potential as a cost-effective, water-efficient, and sustainable farming model that is particularly well-suited to resource-poor communities in Africa (Verner et al. 2021). With appropriate investment, training, and policy support, aquaponics has the potential to become a transformative component of African food systems. It is imperative that smallholder farmers – who remain the foundation of African food production – be at the forefront of these innovations, given their pivotal role in sustaining livelihoods, nutrition, and rural economies.

Despite its potential, aquaponics is still in the early stages of adoption in Africa. Research and implementation efforts are concentrated in a few countries, such as Egypt, Kenya, Malawi, and South Africa, while large-scale empirical evidence on its broader economic and social impacts is scarce (Obirikorang et al. 2021). Key questions remain regarding the scalability of aquaponics, its potential contribution to poverty reduction, and the role of public policy in supporting its diffusion.

This chapter aims to evaluate these issues, building on a case study in Malawi. We assess the microeconomic impacts of the adoption of aquaponics at the farm level and the macroeconomic effects of expanding investments in aquaponics under various public policy scenarios. Our approach is methodical and systematic. We utilize Monte Carlo simulations to assess farm-level profitability and employ a national Computable General Equilibrium (CGE) model, complemented by household survey data from over 12,000 households. This comprehensive strategy enables us to evaluate the economywide impacts on food supply, prices, incomes, and poverty reduction.

The remainder of this chapter is organized as follows: Section 2 provides an overview of aquaponic systems and their development; Section 3 presents the Malawi case study; Section 4 presents the economic analysis of scaling-up aquaponic systems under different public policy programs; Section 5 reviews

the primary conclusions, addresses challenges to scaling, and presents policy recommendations; Section 6 summarizes the key findings and outlines future research needs.

Aquaponics in Global and African Food Systems: Status and Outlook

Concept and global relevance

Aquaponics, a neologism derived from the terms "aquaculture" (fish farming) and "hydroponics" (soil-less plant cultivation), is a specialized form of integrated agriculture-aquaculture (IAA) systems. In aquaponics, fish waste serves as a natural nutrient source for plants, which, in turn, with the support of nitrifying bacteria, purifies the water that is subsequently recirculated back to the fish tanks. This closed-loop system has been demonstrated to minimize waste, reduce the need for chemical fertilizers, and conserve water.

Aquaponics systems directly address today's key sustainability challenges: declining water availability, soil degradation, rising fertilizer costs, and environmental pollution. The recent fertilizer price shocks – driven by global disruptions such as the Russia-Ukraine conflict – have made input-dependent farming increasingly costly (Hebebrand and Glauber 2023). In contrast, aquaponics reduces reliance on external fertilizers and pesticides, while producing both fish (a high-quality protein) and vegetables (rich in vitamins and micronutrients).

Aquaponics contributes to multiple UN Sustainable Development Goals (SDGs), including food security, sustainable resource use, poverty reduction, and gender equality. Benefits of this mode of production include:

- Resource efficiency: up to 90 percent less water use than conventional farming (i.e., "more crop per drop")
- Land use flexibility: production is possible on limited or degraded land
- Continuous output: enables year-round production, irrespective of seasons
- Multiple revenue streams: fish and vegetables generate diverse incomes
- Accessibility for women and youth: less physical labor (no weeding, no soil tilling) and potential for household-level production

Aquaponics systems vary widely, from backyard and demonstration units to large-scale commercial farms (Table 11.1). This diversity enables adaptation to local socio-economic and ecological contexts.

TABLE 11.1—AQUAPONICS PRODUCTION TECHNOLOGIES, MARKETS, FISH REARING PRINCIPLES, AND MAIN PLANT CULTURE PRINCIPLES

Aquaponics system	Markets	Fish rearing principle	Main plant culture principle
Open aquaponics	Home use/direct sales	Batch	Hydroponics and substrate based
Feed Innovation	Women can earn from alternative feed pathways, e.g., black soldier flies or farming forage crops	Limited funds and training block access	Provide microcredit and support cooperatives
Domestic systems (mini/hobby/backyard-coupled)	Home use/direct sales	Batch	DWC, ¹ NFT, ² ebb-flow, media bed
Demonstration aquaponics (e.g., living walls-coupled)	Education, exhibition	Batch ³	DWC, NFT, ebb-flow, media bed, aeroponic, vertical
Commercial Aquaponics and Aquaponics farming			
Small/semi-commercial systems (coupled or decoupled)	Retail/wholesale	Batch/Staggered	DWC, NFT, ebb-flow, drip, aeroponic, vertical, substrate/soil
Large-scale systems (coupled or decoupled)	Wholesale	Staggered ⁴	NFT with full nutrient management, substrate/soil

Source: Table adapted from Palm et al. (2018).

Notes: Decoupled – the aquaculture unit is physically separated from the hydroponic unit. The water with fish effluent does not circulate through all units but is used as the basis of nutrient enrichment with the addition of conventional hydroponic fertilization. Coupled – the water circulates continuously through the system (often single-pump or single-loop systems). This requires relatively stable conditions for fish and plant production and is often technologically limited due to its smaller size and lower investment costs (Baganz et al. 2022).

DWC corresponds to plant bed (deep) water culture. This is a hydroponic system where plant roots are submerged directly in oxygenated, nutrient-rich water that constantly flows slowly through the plant bed. The nutrient film technique (NFT)² refers to a system in which a thin film of nutrient solution flows continuously along sloped channels where plant roots sit. The roots get nutrients from the flowing water while they remain exposed to the air for oxygen. This system requires precise water flow management. Batch³ refers to the rearing of one fish population or one fish age group. Staggered⁴ refers to the rearing of more than one fish age group with intensification of fish production over the whole year.

Global development of aquaponics

Aquaponics is expanding worldwide in response to urbanization, climate change, and rising consumer demand for organic and locally produced foods. Technological innovations – such as digital monitoring, automation, and energy-efficient systems – are further increasing productivity and reducing costs.

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The current innovation leaders in aquaponics include the United States, Australia, Canada, the Netherlands, and Singapore. In these countries, such innovation is supported by government programs, research institutions, and private investment. Globally, the aquaponics industry is projected to grow by over 10 percent annually in the coming years, reflecting its alignment with sustainability and urban farming agendas (Yep and Zheng 2019).

The key drivers behind the increased uptake of aquaponics are:

- Water scarcity solutions in arid and semi-arid regions
- Integration with urban agriculture, often in vertical farming systems
- Consumer demand for organic food, especially in high-income markets
- Government incentives for sustainable agriculture and climate-smart technologies

In summary, aquaponics offers a path towards greater resource efficiency, diversification of production, and sustainability. However, its success is dependent on targeted policy support, careful scaling, and integration into existing systems rather than their replacement. The identification of complementary technologies is an important strategy for improving the system's functionality. This may involve integrating the aquaponics system with other food production systems, such as Black Soldier Fly (BSF) rearing for fish feed production. An approach like this may result in increased efficiency and productivity, reduced

waste disposal, as well as reduced energy and water consumption (Okomoda et al. 2023). Experience has shown that many large-scale aquaponic ventures have encountered difficulties due to their rapid scaling without ensuring system stability, while successful models have often evolved from pilot projects and expanded gradually.

The focus of aquaponics initiatives should be high-value crops and niche markets. Investment in leafy greens, herbs, and specialty vegetables has consistently yielded higher returns than attempting to compete with commodity crops in the market. In addition, it has been demonstrated that direct consumer engagement, such as at farmers' markets and restaurants, is a more viable marketing strategy than selling at wholesale rates.

These findings are important in relation to the implementation of aquaponics in Africa. Across the continent, aquaponics has shown great promise as a sustainable aquaculture system, offering advantages such as water efficiency, adaptability to urban and peri-urban environments, and potential benefits in nutrition and education. However, it has not yet become a mainstream commercial replacement for conventional food production systems. The success of aquaponic systems is contingent on aligning technology with local realities, including affordable energy, local sourcing of feed and fingerlings, hands-on training, modular scaling, and smart financing. Aquaponics farmers should start small, learn fast, and expand only after viability and market conditions have been demonstrated for their context.

The following section highlights the current status, outlook, and expected economic and environmental impacts of aquaponics in Africa.

Aquaponics in Africa: Current status

Aquaponics on the continent is still in the early stages of its development, but interest in the system is growing rapidly. Africa produces approximately 2.8 million tons of fish per year, accounting for about 3 percent of global aquaculture output. The contribution of aquaponics to this figure is currently minuscule, even though its potential to enhance food and nutrition security in resource-constrained environments is widely acknowledged.

Examples of the implementation of aquaponic systems in Africa include:

- Pilot projects and research initiatives in Côte d'Ivoire, Egypt, Ghana, Kenya, Malawi, Nigeria, South Africa and Uganda (Soethoudt et al. 2016; Obirikorang et al. 2021)

- Backyard and small-scale adoption by smallholder farmers and urban dwellers, often for home consumption and local sales
- Commercial experimentation, such as tilapia-vegetable systems in Egypt and South Africa, which have shown promising yields (Table 11.2)

However, several barriers limit the expansion of aquaponics systems, including:

- Moderately high initial investment costs for tanks, pumps, and infrastructure
- Limited technical knowledge among farmers
- Unreliable energy supplies, which increase operational risks
- Restricted access to credit, particularly for smallholders

Despite these challenges, aquaponics is well-suited to the African context as it reduces reliance on scarce water resources, supports year-round production, and offers opportunities for youth and women to engage in agricultural enterprises.

Outlook for Africa

Looking forward, aquaponics has the potential to become an important element of Africa's agricultural transformation, especially under conditions of climate change, desertification, and rapid urbanization. Key opportunities include:

- Integration with renewable energy, particularly solar power, to overcome electricity constraints

- Capacity building and training programs, enabling farmers to adopt and maintain systems effectively
- Development of urban agriculture through aquaponics, enabling the provision of fresh produce to expanding African cities
- Policy support and investment incentives to make systems affordable and scalable for smallholders

TABLE 11.2—FISH AND CROP YIELDS FROM AQUAPONICS IN SELECTED AFRICAN COUNTRIES

Country	Scale	Fish species	Crop grown	Fish biomass	Crop yield	References
Nigeria	Small-scale	Nile tilapia and African catfish	Spinach, eggplant, and Tomatoes	27.9 kg/year	3 kg/year	Benjamin et al. 2020
Ghana	Commercial	Nile tilapia	Maize	—	2.3 t/ha	Frimpong et al. 2017
Côte d'Ivoire	Small-scale	Nile tilapia	Tomatoes	60 kg/month	81 kg/month	Gibellato et al. 2020
Egypt	Commercial		Nalta jute			El-Essawy et al. 2019
Kenya	Small-scale	Nile tilapia	Amaranthus, Cucurbita, and Artemisia		1.1 kg/m ² (Amaranthus), 1.3 kg/m ² (Cucurbita) 1.6 kg/m ² (Artemisia)	Gichana et al. 2018
Egypt	Commercial	Nile tilapia	Lettuce, chives, basil	5-7.5 t/year	7.5 t/year (Lettuce), 3.2 t/year (Basil), 2.6 t/year (Chives)	van der Heijden et al. 2013
Nigeria	Small-scale	Catfish	Pumpkin	160 kg/m ³	43 kg/4 months	Oladimeji et al. 2020
Egypt	Small-scale	Nile tilapia	Bell and cayenne pepper, squash, cabbage, eggplant, brinjal and tomatoes	35.6 kg/m ³ /16 weeks	25 kg (Bell pepper), 37 kg (Cayenne pepper), 50 kg (Squash), 90 kg (Tomatoes), 180 kg (Eggplant, brinjal, and 180 kg plants (cabbage))	Essa et al. 2008
Malawi	Small-scale, experimental	<i>Oreochromis shiranus</i>	Lettuce, cabbage, peppermint, basil	600-1800 kg/year	Cabbage 800-3000 heads/year, Peppermint 80-200 kg/year, Basil 60-150 kg/year	BioServe et al. 2025

Source: Adapted from Obirikorang et al. 2021 (citations in the table are available in the original publication).

Economic analyses of aquaponic production systems in South Africa suggest that financial viability improves with a higher share of plant production relative to fish production, as plant cultivation involves lower operating costs (Babatunde et al. 2021). This insight is critical for designing business models tailored to African smallholders.

Expected economic and environmental impacts

Scaling-up aquaponics in Africa could deliver significant economic and environmental benefits:

- Economic benefits: Diversified incomes from fish and vegetables; premium market prices for fresh organic produce; and increased profitability on small plots of land.
- Employment opportunities: System operations require skilled labor in maintenance, water quality management, and fish feeding, which can spur the creation of new jobs, particularly for youth and women.
- Water and land efficiency: Aquaponics saves up to 90 percent of water used in comparison to conventional farming. The system also enables production in non-arable areas.
- Environmental sustainability: Reduced dependence on chemical inputs; lower pressure on wild fish stocks; decreased deforestation; and reduced soil degradation.
- Urban food security: Production close to consumers reduces import dependence and transportation costs.

At the same time, various challenges remain, including the moderately high start-up capital, limited access to finance, and a steep learning curve for farmers. Addressing these barriers will require targeted policy interventions, such as credit schemes, training programs, and the integration of renewable energy.

Globally, aquaponics is emerging as a climate-smart, resource-efficient agricultural technology. While its adoption is still limited in Africa, its potential to address food insecurity, water scarcity, and employment challenges is substantial. Aquaponics can become a transformative solution for sustainable food production on the continent, provided it receives appropriate policy support, investment, and knowledge transfer.

Aquaponic Systems for Sustainable Small-Scale Farming: A Case Study in Malawi

Technical description of the aquaponic system

Malawi faces significant challenges related to food security and sustainable agriculture due to erratic rainfall, soil degradation, and limited access to resources. Aquaponics presents a viable solution to these issues by offering a closed-loop system that maximizes resource efficiency and minimizes waste. Integrating aquaponics into small-scale farming can help Malawi transition toward a more resilient and sustainable agricultural future.

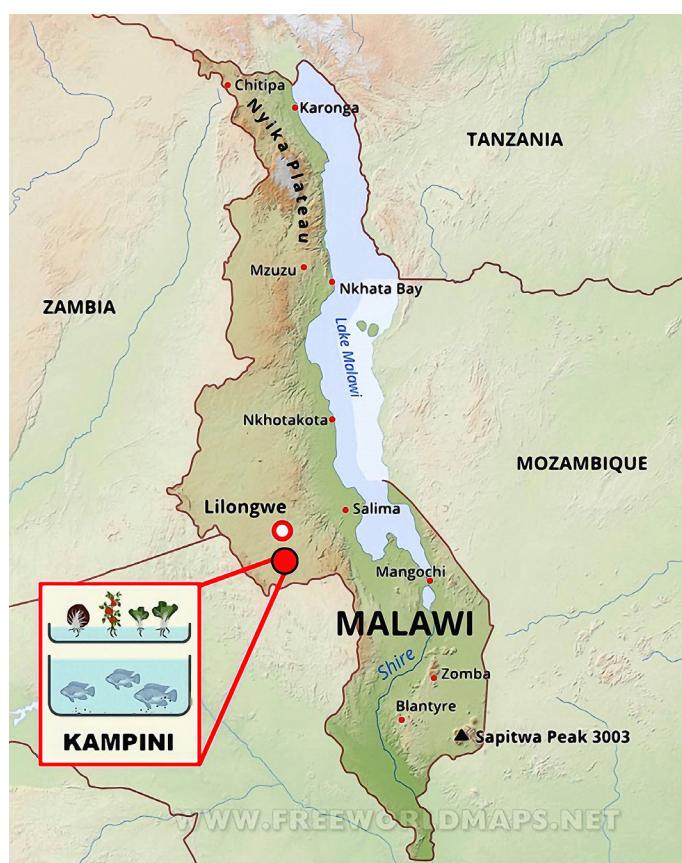
A pilot aquaponics production unit was constructed in Malawi to evaluate the economic and ecological feasibility of an aquaponics system in rural conditions. The unit was built in a typical rural environment with about 25 small villages around it, located about 50 km south of Lilongwe (Figure 11.1). The area is well-watered by a nearby river, ensuring consistent access to water even during the dry season. The production unit was constructed over approximately 5 months, primarily using locally available materials. It has now been in operation for approximately 1.5 years.

The project integrates two innovative, climate-smart technologies: Aquaponics and Black Soldier Fly (BSF) farming. These are both sustainable solutions to key problems in the country's aquaculture and agriculture sectors. BSF farming is a cost-effective solution that provides high-quality protein for fish, poultry, and livestock consumption.

This sustainable method of feed production offers a viable alternative to conventional fish feed, addressing the challenges of high feed costs and waste management. The combination of these two production methods creates a sustainable, biological circular bioeconomy (Figure 11.3). The organic waste from vegetable and fish production is used to rear BSF larvae, which are then used as food for the fish. While aquaponics and BSF production are not new technologies, the integration of both in a single production system represents a novel approach, particularly in the context of developing countries such as Malawi.

Essentially, this technology combines aquaculture, hydroponics, and beneficial bacteria. The negative environmental impacts of aquaculture and hydroponics become advantages within this symbiotic environment. The illustration depicts the material flows and connections between components in the pilot aquaponic production system and integrated BSF farming.

FIGURE 11.1—MAP DEPICTING THE LOCATION OF THE AQUAPONIC PILOT FARM



Source: Adapted from www.freeworldmaps.net 2005-2021. Authors' modifications.

Note: The farm is located about 50 km south of the capital city, Lilongwe, close to the city of Kampini.

This closed-loop system involves the conversion of fish waste into nutrients based on bacterial activities for plant growth. Ammonia (NH_4^+) from the fish waste is initially converted to nitrite (NO_2^-) by Nitrosomonas, followed by Nitrobacter, which then converts it to nitrates (NO_3^-). The nitrates are subsequently absorbed by plants for growth, and the purified water is returned to the fish tank. Any organic waste remaining on the farm can be utilized to cultivate maggots for the BSF. Depending on demand for fish feed, external organic waste may have to be obtained, which has the benefit of contributing toward

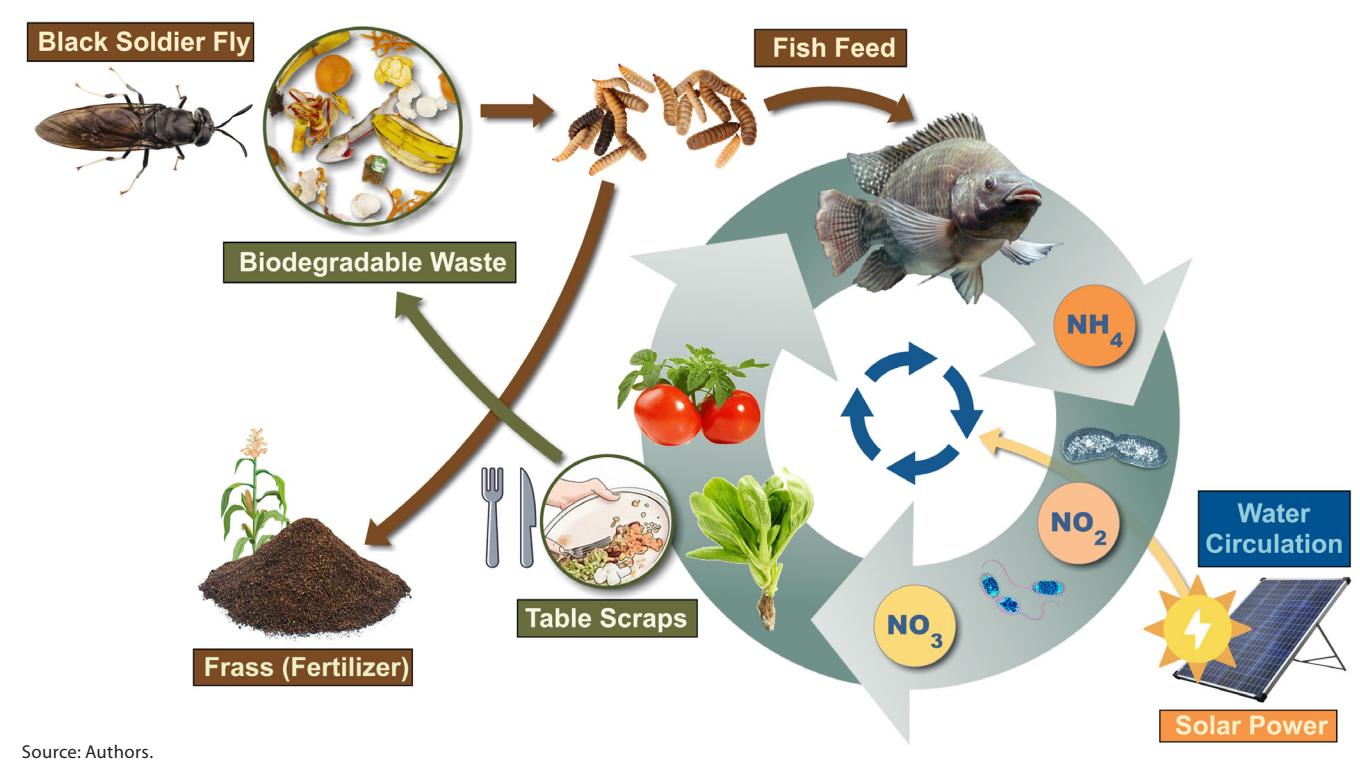
FIGURE 11.2—AERIAL OVERVIEW OF THE PILOT FARM FACILITIES



Note: This drone image, taken on September 4, 2023, provides an aerial view of the pilot farm in Malawi, offering a comprehensive overview of current installations. The aquaponic system is the farm's primary facility, complemented by a small greenhouse for the cultivation of BSF and the rearing of livestock such as rabbits and chickens. The water for the system is sourced from a river near the farm area. Photo Credit: B. Ueberschär.

addressing the pressing issue of waste management in developing countries. The maggots are used as a high-quality protein component in the fish feed produced on-site. The maggots' feces, dubbed "Frass", are a sustainable by-product of insect farming and a valuable organic fertilizer for agriculture. Such a system design corresponds well to the concept of a circular bioeconomy, in which the waste from one process becomes a resource for another. The power required for the water circulation pumps can be supplied by small solar power systems, with batteries providing back-up during nighttime hours.

FIGURE 11.3—THE SYMBIOTIC AQUAPONIC CYCLE



Source: Authors.

The aquaponics system contains two fish tanks, each with a volume of approximately 12 cubic meters. Two plant beds, measuring approximately 6 square meters (5 x 1.20 x 0.30 m), were filled with pebbles as a substrate. Expanded clay, which has a larger surface area than the pebbles and is more suitable for the colonization of nitrifying bacteria, was not available at the time the system was initiated. Sedimentation of solid particles from the fish tanks was conducted upstream before the water from the fish tanks was directed back through the plant beds.

The pilot farm was constructed to assess various production methodologies and parameters. At the start of the operation, a variety of vegetable production methods were tested, including flood and drain, substrate-based production,

and the nutrient film technique (NFT). The objective was to assess the most suitable approach for local environmental conditions or whether a hybrid form was required.

The area where the farm is located has no grid connection. A solar power supply system was therefore installed to ensure uninterrupted electricity supply. This consisted of two solar panels with a peak output of 410 watts each and four 12-volt LiFePO₄ batteries with a capacity of 50 Ah each. Every two batteries were connected in series to provide a 24 V direct current source for the 24-volt water pumps in the system.

The BSF production is undertaken in a small greenhouse equipped with a love cage for mating, rearing boxes for the larvae, and collection containers for organic waste. The facility is also

equipped with processing equipment for organic waste, including shredding and homogenization. For every ton of organic waste, BSF larvae can produce up to 200 kilograms of protein. The size of the BSF production unit was designed to meet the anticipated demand for maggots used as fish feed.

Tilapia (*Oreochromis shiranus*) were used as the stocking fish. The plant beds have yielded successful harvests of tomatoes, basil, lettuce, sweet pepper, and cabbage. The system is still in the pilot phase, and the study team is working to collect data for optimized operations. A group of students from the University of Lilongwe (LUANAR) has been assigned to collect data on the pilot farm for their Bachelor's or Master's thesis.

Micro-economic analysis of aquaponic and barrelponic systems

Based on this case study, the study team derived the input-output (I-O) coefficients that describe this aquaponic unit's production technology. Table 11.3 shows the I-O coefficients. The study team derived separate I-O coefficients for the BSF unit and the aquaponics unit. For the aquaponics unit, we separated the variable inputs for crop and fish production. Table 11.3 presents the total inputs and outputs for the designated production unit on an annual basis. Furthermore, we have included normalized I-O coefficients to facilitate more accurate comparisons across technologies. Specifically, we use aggregated crop output for the normalization of I-O coefficients for the aquaponics unit. Similarly, we use aggregated feed output measured in kilograms of dry larvae for the normalization of I-O coefficients for the BSF unit.

The initial investment required for the establishment of the aquaponic unit in this case study was US\$¹ 1,610. This is equivalent to an annual capital expenditure of \$213, calculated based on an assumed real interest rate of 5 percent and a depreciation period of 10 years. The investment plan included the construction of fish tanks, plant beds, water pumps, and a solar power system. In addition, the investment cost for the BSF unit was \$679, which included the greenhouse construction. The aquaponic unit is powered by a solar system that is set up for this purpose. The total investment cost was equivalent to an annual capital expenditure of \$88, based on our calculated interest rate and depreciation period. Capital costs covered all the costs of installing the aquaponic and BSF units, including materials, labor, and transportation. Further, maintenance costs were included in capital costs in the input-output tables.

The costs involved in training farmers to operate aquaponic systems were not included in the capital costs. The impacts of farmer training costs on the overall evaluation of public investments in these systems will be discussed in Section 5 of this chapter.

Total variable costs for the aquaponic unit came to \$583. This included a \$524 variable cost for fish production, consisting of \$459 for the fingerlings and \$65 for self-produced feed. A smaller proportion of variable input costs was associated with crop production. This only included the cost of seeds, which amounted to \$59. Labor costs were not included in variable costs, based on the

TABLE 11.3—INPUT-OUTPUT TABLE FOR AQUAPONIC SYSTEM (2X12 M³ FISH TANKS COMBINED WITH TWO 6 M² PLANT BEDS)

Inputs	Unit	Number of units per year	Price (\$)	Costs (\$)
Fish production				
Labor	Person per year	2		
Fingerlings	Number	13,000	0.04	459
Feed	Kg	2,000	0.03	65
Crop production				
Labor	Person per year			
Seeds	Kg	2	2.8	5.5
General				
Capital	\$	213	1	212.5
TOTAL COSTS	\$			742
Outputs				
Lettuce	Kg	1,000	5	4,706
Tilapia	Kg	3,000	1	1,765
TOTAL REVENUE	\$			6,471
GROSS MARGIN	\$			5,728

Source: Authors.

assumption that total labor inputs would be provided by members of the household that owned the aquaponic production unit. The study team was keen to calculate actual profits realized by the farm households operating the aquaponic systems and not the hypothetical profits, which could be calculated by taking all input costs into account. Furthermore, maintenance costs are included among other costs in the input-output tables.

The total variable costs of the BSF unit were \$353. These costs included materials, maintenance, and other expenses. Labor was not treated as a variable cost, as it was assumed that all labor inputs would be provided by the family.

¹ All dollars are US dollars.

TABLE 11.4—INPUT-OUTPUT TABLE FOR BSF SYSTEM
(GREENHOUSE PRODUCTION UNIT WITH A CAPACITY OF 200 KG OF PROTEIN PER TON OF ORGANIC WASTE)

Inputs	Unit	Number of units per year	Price (\$)	Costs per year (\$)
Fish production				
Labor	Person per year	1		
Other costs	\$	60,000	1	60,000
Capital	\$	353	1	353
TOTAL COSTS	\$			60,353
Outputs				
Fresh Larvae	Kg	3,204	50.00	160,200
Dry Larvae	Kg	920	0.00	0
Frass	Kg	4,368	0.07	308
Total feed output	Kg. eq. dry larvae	2,692	0.03	88.0
TOTAL REVENUE	\$			160,508
GROSS MARGIN	\$			100,155
Source: Authors.				

Further, energy was not included in the variable costs because all energy for both the aquaponic and BSF units would be provided by the solar system and was therefore covered under capital costs.

In addition, the study team compared the aquaponics unit in our case study, a small-scale industrial unit typically owned and operated by five households, with a popular individual barrel aquaponics (barrelponic) system.² This system has been designed as a promising option for rural and urban households with limited land. Table 11.4 shows the technical input-output coefficients for an individual barrelponic system. The system consists of a simple barrel that functions as a fish tank and a small plant bed. It does not include an integrated BSF unit, so the fish feed would need to be purchased.

Based on the literature, the investment costs to set up the unit for the barrelponic system were approximately \$612. This is equivalent to an annual

TABLE 11.5—INPUT-OUTPUT TABLE FOR BARRELAPONIC SYSTEM (1 BARREL, SMALL PLANT BED)

Inputs	Unit	Number of units per year	Unit Price (\$)	Costs (\$)
Fish production				
Labor	Person per year	1		
Fingerlings	Number	66	0.05	3.3
Feed	Kg	20	0.07	1.3
Crop production				
Labor	Person per year	1		
Seeds	Kg	0.8	2.8	2.2
General				
Capital	\$	79.8	1	79.8
TOTAL COSTS	\$			86.6
Outputs				
Lettuce	Kg	130	2.7	349.2
Tilapia	Kg	20.2	5.0	101.0
TOTAL REVENUE	\$			450
GROSS MARGIN	\$			464
Source: Authors.				

capital cost of \$80, based on a real interest rate of 5 percent and a depreciation period of 10 years. Investments included the barrel used as a fish tank, the construction of a small plant bed, and the installation of water pumps and a solar system that power the entire unit. Variable costs for the barrelponic unit came to \$6.20 annually. This figure consisted of the variable costs for fish production of \$4 (i.e., \$3 for fingerlings and \$1 for purchased feed) as well as variable costs for crop production (purchased seeds) at \$2.20. Labor costs for the barrelponic system were not included in variable costs under the assumption that total labor inputs would be provided by the family owning the production system. Maintenance costs were included in the capital costs,

2 A Guide to Barrel Aquaponics System. <https://tinyurl.com/33ztuvmm>. Accessed August 2025.

whereas the cost of training farmers to operate the barrelponic system was not included in the I-O tables. These farmer training costs and their impacts on the overall evaluation of public investments in barrelponic systems will be discussed in Section 5 of this chapter.

The study team also conducted a comparison of the barrelponics and the small-scale industrial aquaponics systems. The profit and cost shares for both systems were calculated. As Table 11.6 shows, the cost structures of barrelponic and aquaponic systems are rather different. Specifically, the largest cost item for the barrelponic system is capital, with a total cost share of 92 percent, while the share of capital costs for the aquaponics system is 26.7 percent. The main reason for the comparatively higher capital costs of the barrelponic system is that it is not feasible to purchase a solar power system with a lower capacity to meet its energy requirements.

The highest total cost share for the aquaponic system consisted of the variable costs of fish production, which accounted for approximately 66 percent of total costs. The variable cost predominantly associated with fish production is attributable to the initial investment in fingerlings, which accounts for 57.7 percent of total costs. While variable costs of fish production are significantly lower for the barrelponic system (total cost share of 5.3 percent), the relative cost shares of different input components are rather similar. The relative cost share of fingerlings is 71.6 percent and 87.5 percent of the total variable cost in barrelponic and aquaponic systems, respectively. It is also worth noting that prices for fingerlings are higher in barrelponic systems, as aquaponic systems have much higher demand and can consequently negotiate better deals.

A comparison of the cost structures for the barrel pond system and the aquaponic unit reveals a marked difference in cost allocations for fish feed. The barrel pond system allocates a substantially higher percentage of its total costs to fish feed (28 percent), while the aquaponics unit allocates a significantly lower

TABLE 11.6—COST AND REVENUE SHARES FOR AQUAPONIC AND BARRELAPONIC SYSTEMS (IN %)

Inputs	Profit share		Cost share	
	barrelponic	small-scale aquaponic	barrelponic	small-scale aquaponic
Fish production				
Total variable costs			5.32	65.89
	Labor			0.00
	Fingerlings		3.81	57.67
	Feed		1.51	8.22
Crop production				
Total variable costs			2.54	7.4
	Labor		0.0	0.0
	Seeds		2.5	7.4
General			92.1	26.7
	Capital		92.1	26.7
TOTAL COSTS		23.82	14.02	100.00
Outputs				
	Lettuce	83	83	
	Tilapia	31	31	
TOTAL REVENUE		114	114	
GROSS MARGIN		100.00	100.00	420
Source: Authors.				

percentage of its total costs to fish feed (12.5 percent). This is due to the fact that the barrelponics system is not integrated with a BSF unit. Consequently, fish feed must be procured from the market at a significantly higher price. For instance, the average market price for fish feed is nearly double the internal price arising from BSF-based feed production (Tables 11.4 and 11.5).

Finally, while both systems are highly profitable with a profit-cost relationship of 4 and 7 percent for the barrelponic and aquaponic systems, respectively,

profitability for the aquaponic system is much higher than that for the barrelponic system. However, when interpreting profit-cost relationships, it should be noted that the current costs do not include labor. Evaluation of profitability in terms of profit per labor unit yields a value of \$363 per labor unit per year for the barrelponic system, while the aquaponic system yields a value of \$1,418 per labor unit per year. In 2023, Malawi's per capita income was \$630, which means that the aquaponic system is competitive within that country's context.

Assessing the Macroeconomic Impacts of Aquaponics in Malawi

Building on the data from the Malawi case, the study team evaluated the potential economic viability of an aquaponics system for fish and vegetable production in Africa. The next section addresses the economic potential of aquaponic and barrelponic systems using Malawi as a case study.

Besides assessing the profitability of aquaponic and barrelponic systems at the micro-level, it will be important to evaluate the impact of public investments promoting these systems at the macro-level. To address this question, we proceed as follows. First, we assume that a public policy program will provide a state guarantee for the credit needed to finance private investment in aquaponic systems. State guarantees will significantly increase access to credit among poor farming households. Second, to mimic the risk of investing in an aquaponic system, we apply a Monte Carlo (MC) simulation to derive a distribution of the gross margins for an aquaponic system. To facilitate our analysis, we assume that MC simulations can be represented by a normal distribution of gross margin. Let 'G' denote the average gross margin, while 's' denotes the standard deviation. We can then draw from the normal distribution $g \sim N(G, s) = F(g)$ to mimic the uncertain gross margin 'g' of the aquaponic system. Further, we can calculate the probability that a farm household is unable to pay back the investment credit as $Prob(G, s)[g < 0]$. Accordingly, a public program guaranteeing credits for farm-households to invest in aquaponic systems has the expected costs of $Prob(G, s)[g < 0] * K$, where 'K' denotes the credit taken to finance the aquaponic investment. Assuming total public expenditures allocated to the aquaponic support program amount to 'M', then the maximum number of farm-households that can be targeted under this program is: $n = \frac{M}{(Prob[g, 0]K)}$. Third, we assume that the aquaponic program only targets poor rural households. For each household, 'h', targeted under the aquaponic program, we can

calculate the expected probability that participation in the aquaponic support program will shift the household 'h' out of poverty as:

$$E_h (\text{h gets out of poverty}) = \int F(g) \delta_{gh} dg \quad (1)$$

where δ_{gh} denotes Kronecker delta with $\delta_{gh} = 1$, if $Y_h + g > Y_{pov, h}$. $Y_{pov, h}$ denotes the poverty line of household 'h', i.e., the household income which guarantees that the average income per household member of household 'h' is above the poverty line. Finally, let ' w_h ' denote the statistical weight of household 'h' in the socio-economic household survey. We can then calculate the overall expected probability that a randomly selected poor household will be lifted out of poverty by the aquaponic program:

$$E(\text{out of poverty}) = \sum_h w_h E_h (\text{h gets out of poverty}) \quad (2)$$

Overall, the expected impact of a public policy program supporting aquaponic investments of 'K' per aquaponic system via state guarantees with a total budget of 'M' implies the following expected poverty reduction numbers ($dPov$):

$$dPov = n * E(\text{out of poverty}), \text{ where } n = \frac{M}{Prob(g, s)K} \quad (3)$$

So far, our analysis has focused on the micro-level only and has neglected any economywide responses at the macro level. However, depending on the scale of implementation of the support program, the supply of crops and fish produced by the aquaponic systems could rise.

Increases in domestic supply imply a decrease in domestic farm-gate prices for fish and crops in line with general market dynamics. As such, we used a national computable general equilibrium (CGE) model for Malawi based on a Social Accounting Matrix (SAM) from 2023 (IFPRI 2024) to estimate a metamodel that simulates domestic price effects arising from exogenous supply shocks (for a detailed explanation of metamodeling techniques applied to CGE models, please see Ziesmer et al. 2022 and 2023). Based on the metamodel, we estimate farm-gate price effects, dP/P_0 , induced by the policy support program as follows:

$$\frac{dP}{P_0} = \theta^m(p) \frac{dS}{D_0} \quad (4)$$

where P_0 denotes the farm-gate price index for crops in the base run, while D_0 denotes the aggregated domestic demand for vegetables, respectively. $\theta_m(p)$ is the local elasticity of demand as a function of the market price derived from the metamodel of the national CGE.

As shown in Table 11.7, Malawi's total GDP in 2023 was \$12.7 billion. This results in a per capita income of \$632, given a total population of 20.1 million people. Assuming the state budget is 23 percent of total GDP results in a budget of approximately \$2.9 billion. Based on the assumption that the Malawian government allocates 0.1 percent to 2 percent to the aquaponic support program,³ we can calculate the maximum number of poor households that can be targeted if the public support program directs investments toward small-scale aquaponic or barrelponic systems. For the small-scale aquaponic system a range from 119,000 to 1.76 million households that can be targeted, assuming investments in small-scale aquaponic systems are supported. If the public policy support program is focused on barrelponic systems, the maximum number of households that can be targeted ranges from 30,000 to 606,000. The difference in outcomes for the small-scale aquaponic system relative to the barrelponic system is based on the understanding that the probability that investments do not succeed is almost double for the barrelponic system (15.8 percent) in comparison to the small-scale aquaponic system (7.6 percent). Moreover, it is important to note that investments in the aquaponic system involve five households, whereas only one household is involved in the barrelponic system.

To understand the impacts on poverty, we first calculated the expected probability that a randomly selected poor household that invested in an aquaponic system would realize an additional household income enabling them to escape poverty (i.e., the total household income is above the national poverty line). We calculate this expected probability using Formula 2 above based on the micro-household survey data. The micro-survey data include a representative socio-economic household survey from 2019, which covered 12,500 rural and urban households (NSO 2020).

Table 11.7 shows that the expected probability for poor households to get out of poverty, under the public program supporting investments in aquaponic systems, is 81.1 percent. This figure ignores induced price responses at the macro-level. When market responses are taken into account, this probability reduces significantly to 43 percent. The reduction in this probability arises from the anticipated decrease in farm-gate prices for the crops that households with aquaponic systems produce. As reported in Table 11.3 above, the annual crop production per aquaponic system is approximately one ton. Therefore, if the Malawi government allocated 2 percent of the total state budget to the aquaponic support program, then 353,000 small-scale aquaponic systems would be implemented, each producing one ton of vegetables per year. This would result in an additional supply of 297 thousand tons of vegetables per year (i.e., $353 * 1 * (1 - 0.157)$). Given the domestic demand of roughly 200,000 tons

TABLE 11.7—SIMULATED IMPACT ON POVERTY OF PUBLIC EXPENDITURE FOR POLICY SUPPORT OF SMALL-SCALE AQUAPONIC SYSTEMS

		Public expenditure for aquaponic support program [M]			
		in % of total state budget			
		Unit	0.1	0.5	1
Share of targeted poor household	In %	6.7	33.6	67.2	100.0
Excluding domestic market response					
Probability to get out of poverty	In %	81.1	81.1	81.1	81.1
Poverty reduction	In %	5.4	27.2	54.5	81.1
Including domestic market response					
Probability to get out of poverty	In %	78.6	68.5	56.0	43.4
Poverty reduction	In %	5.3	23.0	37.6	43.4

Source: Authors.

³ Please note that the total public expenditure allocated to promote inclusive growth in the agriculture amounts to roughly 11 percent in Malawi. Accordingly, it makes sense to analyze investments in the aquaponic system in the 0.15-2 percent range. One of the main goals of investments in agricultural growth is poverty reduction, so it makes sense to investigate the poverty reduction effects arising from public investments in aquaponic systems.

TABLE 11.8—SIMULATED IMPACTS ON POVERTY FROM PUBLIC EXPENDITURE FOR POLICY PROGRAMS SUPPORTING INVESTMENT IN BARRELPONIC SYSTEMS

		Public expenditure for barrelponic support program [M]			
		in % of total state budget			
		Unit	0.1	0.5	1
Share of targeted poor household	In %	1.7	8.6	17.2	34.3
Excluding domestic market response					
Probability to get out of poverty	In %	50.0	50.0	50.0	50.0
Poverty reduction	In %	0.9	4.3	8.6	17.2
Including domestic market response					
Probability to get out of poverty	In %	48.4	43.4	36.8	30.2
Poverty reduction	In %	0.8	3.7	6.3	10.4
Source: Authors.					

of vegetables per year, this represents an increase of almost 150 percent. Based on our metamodeling estimates, this implies a roughly 75 percent decrease in domestic prices, corresponding to an aggregated demand elasticity of -1. This implies a reduction in expected profits from the aquaponic systems, and a corresponding reduction in the expected probability of poor households escaping poverty, from 81.1 to 43.4 percent. Assuming only 1 percent of the total state budget was allocated to the aquaponics support program, total vegetable supplies would only increase by 237 thousand tons, resulting in a decrease in domestic farm-gate prices of 50 percent. Expected profits and the expected probability of poor households escaping poverty would decrease to only 56 percent. Further, the expected probability of escaping poverty would amount to 68.5 percent, assuming the aquaponic support program were implemented at a smaller scale of 0.5 percent of the state budget. If the allocation were to drop even further to 0.1 percent of the total state budget, then the expected probability would

rise to 78.6 percent (Table 11.8). Allocations of 0.5 percent or 0.1 percent of the total budget to support investments in aquaponic systems would result in an increased supply of vegetables by 118,000 or 24,000 tons, respectively.

The induced price decreases are less pronounced for barrelponic systems when compared against investments in small-scale aquaponic systems. As Table 11.8 shows, the expected probability to escape poverty for a randomly selected poor household amounts to 50 percent if market responses at the macro level are ignored. The expected probability is lower for barrelponic systems in comparison to small-scale aquaponic systems, because the expected profit per household is lower, i.e., \$364 for barrelponic systems compared to \$1,135 for aquaponic systems. However, since induced supply increases are also significantly lower for barrelponic systems, e.g., with annual lettuce production amounting to 130 kg per household, increases in total national production range from 4,000 to 79,000 tons per year. This corresponds to roughly 2 percent to 40 percent of total annual demand. In line with these lower production numbers, induced price responses are significantly lower when compared to aquaponic systems.

Overall, a comparison of Tables 11.7 and 11.8 shows that supporting small-scale aquaponic systems is significantly more efficient than supporting barrelponic systems, as the induced poverty reduction under the former is four to six times higher than the latter. It is also important to note that government support for both barrelponics and aquaponic systems is significantly more effective and efficient at reducing poverty than targeted income transfers. Achieving equivalent poverty reduction numbers via targeted transfers would require almost 7 and 14 times more public spending than allocations to support barrelponic and aquaponic investments, respectively.

Challenges and Policy Recommendations for the Scaling-Up of Aquaponic Systems

Aquaponic production systems offer a sustainable and efficient method of food production. This innovative approach has the potential to address food security challenges, optimize water usage, and promote sustainable agriculture in Africa. However, the scaling-up of aquaponic systems in Africa faces several challenges. Overcoming these challenges requires strategic interventions and a vision for the future.

Challenges to the scaling-up of aquaponic systems in Africa

Despite the promise of aquaponics, several obstacles hinder its widespread adoption across Africa. These challenges include economic, technical, infrastructural, and market-related barriers. One of the major barriers to the adoption of aquaponics is the capital required to set up the necessary infrastructure. The construction of tanks, pumps, filters, and other infrastructure requires significant investment. Further, this financial burden is compounded by the costs associated with monitoring equipment and renewable energy sources, such as solar power. Although total investment costs are not high, especially when compared to the expected revenue, the share of investment costs in the total gross margin ranges from 23 percent for barrelponic systems to 15 percent for small-scale aquaponic systems. However, the majority of small-scale farmers lack the financial resources to cover these investment costs and are often unable to access credit markets. Public policy programs that provide credit guarantees from the state are therefore essential if poor farmers are to gain access to credit at relatively low interest rates, e.g., at 5 percent.

Managing an aquaponic system calls for expertise in both aquaculture and hydroponics, as well as a firm grasp of water chemistry, nutrient cycling, and system maintenance. Many farmers lack the necessary technical expertise, and training opportunities in African countries are limited. Without sufficient knowledge transfer, farmers may face challenges in maintaining efficient and productive systems.

Ensuring a reliable supply of water and electricity is paramount to the success of aquaponic systems. However, many regions in Africa face frequent power outages and water shortages. Aquaponic systems rely on continuous water circulation and aeration, so power disruptions can negatively impact fish and plant health, leading to crop failures and financial losses.

The availability of high-quality fish fingerlings, fish feed, and essential nutrients for plant growth is inconsistent in many regions. Farmers often depend on imported inputs, which increases their costs and impacts the sustainability of their operations. This challenge is further compounded by the absence of local suppliers.

Despite these challenges, the future of aquaponics in Africa holds significant promise. Several factors suggest that aquaponics can play a vital role in

the continent's agricultural transformation. As climate change impacts and mounting concerns over water scarcity increase, there is a growing demand for sustainable and water-efficient farming methods. Aquaponics is a sustainable agricultural solution that aligns with Africa's need for climate-smart practices. The continued growth of urban populations (United Nations 2019) expands the rising demand for fresh, locally sourced food. Aquaponics is particularly well-suited for urban and peri-urban areas due to its spatial efficiency and ability to produce food in close proximity to consumers. Vertical farming and rooftop aquaponic systems offer potential solutions for feeding urban populations. Advances in technology, automated water quality monitoring, and solar-powered systems are making aquaponics more accessible and efficient. These innovations can help mitigate some of the technical challenges and improve system management.

An increasing number of governments, non-governmental organizations (NGOs), and international organizations are recognizing the potential of aquaponics for food security and poverty alleviation. Programs that aim to support small-scale farmers and entrepreneurs in the adoption of aquaponic farming are increasingly emerging. The Malawi case presented in this chapter is an example of such progress.

Aquaponic systems have the capacity to produce organic and pesticide-free food, which has significant global demand. With proper certification and branding, African farmers can access lucrative export markets in the future to supply premium-quality fish and vegetables.

Policy recommendations for scaling-up aquaponic systems in Africa

To fully realize the benefits of aquaponics, a combination of financial, technical, policy, and market-driven strategies must be employed.

Large-scale adoption of aquaponics in African countries calls for the design and implementation by governments, international organizations, and the private sector of well-structured policies that address financing, training, infrastructure, and market access gaps. National policymakers should embrace aquaponics as part of their agricultural and food policies and programs, while prioritizing initiatives that bring these practices to particularly low-income and resource-poor smallholder farmers, with support from agricultural extension programs. One of the primary barriers to the adoption of aquaponics in Africa

is the high cost of initial investments. Further, scaling-up aquaponic systems requires technical and market infrastructure. To address these challenges, African governments should introduce the following public policy measures:

- Public policy supporting access to credit markets for small-scale farmers: The government should provide public financial resources to support state guarantees for farmers investing in aquaponic systems. This would enable poor farmers to access credit at reasonable interest rates. Additionally, financial institutions should develop microfinance products and low-interest loans specifically tailored for aquaponics farming, enabling small and medium-scale farmers to access capital.
- Public-Private Partnerships (PPPs): Encouraging partnerships between the government and private investors can facilitate the development of commercial aquaponics ventures, in addition to fostering innovation and scaling-up operations.

Aquaponics requires specialized knowledge in fish health management, plant nutrition, water chemistry, and systems maintenance. Most farmers in Africa lack the necessary expertise to successfully operate such systems. To address this gap, policymakers should:

- Develop training programs: Governments, universities, and agricultural extension services should offer training programs focused on aquaponics techniques, system maintenance, and best practices.
- Integrate aquaponics into agricultural education: Agricultural colleges and universities should incorporate aquaponics into their curricula to equip future farmers with the necessary skills.
- Support research and innovation: Governments should invest in research facilities to study locally adapted fish species and crops suitable for aquaponics. Research should focus on cost-effective system designs that can operate efficiently in different climatic conditions across Africa.
- Create knowledge-sharing platforms: Establishing online platforms and farmer cooperatives for knowledge exchange can facilitate the spread of aquaponics expertise.

The successful implementation of aquaponics depends on reliable infrastructure, including water supply, electricity, and market connectivity.

- Enhancing water and energy access: Aquaponics is a water-efficient production system, but it requires a steady supply of quality water. Governments should invest in boreholes, rainwater harvesting systems, and renewable energy solutions (such as solar-powered pumps) to ensure reliable system operations.

For aquaponics to thrive in Africa, clear policies and regulations must be established to ensure food safety, environmental sustainability, and quality control. Key recommendations include:

- Developing regulations specific to aquaponics: Policymakers should create guidelines that define best practices for fish and plant health management, waste disposal, and biosecurity.
- Ensuring food safety compliance: Establishing clear food safety standards and certification processes will help aquaponics farmers access premium markets, including export markets.
- Monitoring water use and environmental impacts: Regulatory frameworks should include measures to prevent water contamination, ensure responsible waste management, and protect biodiversity.

Public perceptions and awareness play a crucial role in the adoption of aquaponics. Many consumers and farmers in Africa are unfamiliar with the benefits of aquaponics, which can hinder acceptance.

- Launch public awareness campaigns: Governments and NGOs should run educational campaigns that highlight the sustainability and nutritional benefits of produce from aquaponics systems.
- Encourage urban and community aquaponics: Promoting small-scale urban and community aquaponics projects can serve as demonstration models, spurring wider adoption.
- Engage conventional farmers: Enrolling conventional farmers into pilot programs and showcasing successful case studies can help integrate aquaponics into existing agricultural practices.
- Work at the community level: Identify opportunities to incorporate aquaponics into local development planning and climate change adaptation, such as the design of local adaptation plans. Ensuring broad participation by

women and other marginalized groups by designing training programs that are tailored to their needs and contexts is essential. This may require setting targets for participation and outcomes for different groups.

Summary

This chapter has examined the potential of aquaponic systems as a climate-smart and resource-efficient agricultural innovation for Africa. Although adoption remains limited, experiences from Egypt, Kenya, Malawi, and South Africa highlight the capacity of these systems to enhance food security, nutrition, and rural livelihoods. A pilot project in Malawi confirmed the feasibility of aquaponics in rural settings, particularly when combined with Black Soldier Fly (BSF) farming, which provides a cost-effective and sustainable source of fish feed. Cost-benefit analyses demonstrated that both small-scale aquaponic units (operated by groups of approximately five households) and household-level barrelponic systems generate positive gross margins. However, small-scale aquaponics was shown to be substantially more efficient due to the lower costs of feed (through BSF integration) and economies of scale. Conversely, barrelponic systems rely on purchased commercial feed and therefore exhibit lower profitability.

To assess the broader impacts of widespread adoption of aquaponics systems, farm-level profitability was evaluated under uncertainty using Monte Carlo simulations, complemented by a Computable General Equilibrium (CGE) model to capture economywide price effects. Key findings from this assessment follow:

- Poverty reduction at the household level (without price effects): Adoption of a small-scale aquaponic system is associated with an 81 percent probability that a poor household escapes poverty. For barrelponics, this probability declines to 50 percent.
- Impact of market responses (price effects): Large-scale aquaponics support programs (which receive 2 percent of Malawi's state budget) are associated with sharp increases in vegetable supplies, reductions in farm-gate prices by up to 75 percent, and a decline in the probability of exiting poverty to 43 percent. For barrelponics systems, this same probability declines more gradually to approximately 30 percent, reflecting their smaller aggregate contribution to vegetable supplies.
- Sensitivity to the scale of public expenditure:

- With allocations of 0.1 percent of the national budget (approximately \$2.9 million), aquaponics lifts approximately 6.7 percent of poor households out of poverty with negligible price effects.
- With budgetary allocations of 0.5 percent, the poverty reduction effect rises to 23 percent.
- With budgetary allocations of 1 percent, poverty reduction reaches approximately 38 percent, though downward price pressure intensifies.
- At 2 percent budget allocations, approximately 43 percent of poor households benefit, but profitability declines due to strong price effects.
- Barrelponic systems achieve far smaller impacts. Poverty reduction effects are 0.8 percent with 0.1 percent budget allocations and 10 percent with 2 percent budgetary allocations. This makes barrelponics four to six times less effective than aquaponics.

The analysis further shows that public credit guarantees for aquaponics are substantially more cost-effective than direct income transfers, requiring 7 to 14 times less public expenditure to achieve equivalent poverty reduction rates. Nonetheless, macroeconomic simulations underscore that excessive expansion of aquaponics systems may undermine market profitability and erode household-level gains.

Overall, aquaponics demonstrates strong potential to advance food security, income diversification, and resource efficiency in African agriculture, particularly in the context of climate change, water scarcity, and rapid urbanization. The Malawi case study illustrates that aquaponics can achieve significant poverty reduction at scale, but outcomes depend critically on policy design. Specifically:

- Moderate support (0.5-1 percent of public expenditure) yields large poverty-reduction effects without destabilizing markets.
- Small-scale aquaponic systems, especially when integrated with BSF-based feed, are more effective than barrelponics in delivering household income gains.
- Effective policies should integrate financial support, technical training, and renewable energy to address barriers such as capital intensity, limited expertise, and unreliable infrastructure.

- Market development through regulation, quality standards, certification, and consumer awareness campaigns will be essential to sustain demand and profitability.

In conclusion, aquaponics is not a universal solution, but when scaled strategically and embedded in coherent policy frameworks, it can become a transformative agricultural innovation. The Malawi case study provides evidence that aquaponics can significantly reduce poverty while promoting climate resilience and resource efficiency more effectively than many conventional interventions. However, scaling strategies will have to carefully balance household benefits with market dynamics.