CHAPTER 2

# Moving the Technology Frontiers in African Agrifood Systems: An Analytical Framework

Christian Henning and John Ulimwengu

## Introduction

The transformation of African agrifood systems stands as one of the most urgent and complex development challenges of the 21st century. With over 60 percent of the continent's population relying on agriculture for their livelihoods, the sector holds tremendous potential to serve as a catalyst for broad-based economic growth, poverty alleviation, and food and nutrition security. This potential, however, remains largely untapped. Agricultural productivity across Sub-Saharan Africa (SSA) continues to stagnate; despite decades of reform efforts and policy commitments, it lags significantly behind other regions of the world (Ulimwengu et al. 2025).

The persistence of low yields, high postharvest losses, fragmented markets, and rising vulnerability to climate change suggests that past strategies have been insufficiently systemic and insufficiently transformative. Indeed, the dominant development paradigm has often focused narrowly on input subsidies, isolated technology transfers, or ad hoc institutional reforms, without fully addressing the structural and political-economic constraints that inhibit the diffusion of innovation and inclusive growth.

This paper offers a comprehensive analytical framework for rethinking the innovation landscape in African agriculture. It builds on the premise that technological innovation, if properly guided, embedded, and governed, can serve as a lever to overcome key inefficiencies across the entire agrifood system. Unlocking this potential, however, requires moving beyond a simplistic, input-driven view of productivity. It demands a multilayered understanding of the interplay between science, policy, institutional capacity, and sociopolitical context.

At the heart of this is a typology of technologies that categorizes innovations into four broad families:

- Conventional agricultural technologies, such as improved seeds, fertilizers, and mechanization
- Digital technologies such as artificial intelligence (AI), mobile platforms, blockchain, remote sensing, and precision agriculture
- Biological innovations such as gene editing, biofortification, aquaponics, and insect farming
- Financial and social innovations

These technologies are not analyzed in isolation; rather, they are investigated as part of an interconnected food system approach that spans production, storage, processing, distribution, retail, and consumption. This systemic perspective allows for the identification of both leverage points and bottlenecks across value chains; it also provides a basis for crafting targeted interventions.

Crucially, the paper situates technological adoption within the historical context of global innovation policy trajectories. A comparative analysis of Asia and Latin America shows that strategic public investment, coupled with institutional reform and effective governance, has yielded sustained improvements in agricultural total factor productivity (TFP), poverty reduction, and rural development. African countries have struggled to emulate this trajectory; however, they often rely on growth models that are characterized by land expansion rather than efficiency gains or innovation.

To explain this divergence, the paper introduces a three-pathway model of innovation-driven growth:

- Technological progress (TP): Generating and employing new technologies to shift the production frontier
- Technical efficiency (TE): Closing the gap between actual and potential output through better use of existing technologies and practices
- Transaction cost reduction (TC): Addressing market, informational, and institutional barriers that prevent farmers (particularly smallholders) from accessing inputs, services, and markets

Each of these pathways is mapped to corresponding public policy domains, from research and extension systems to digital infrastructure and market governance. The paper further introduces a formalized political economy model to illustrate how governments can, under budget constraints and model uncertainty, optimize policy choices to maximize sustainable development outcomes. This framework recognizes that governments rarely have perfect information and are often constrained by institutional inertia, competing interests, and limited analytical capacity.

The paper, in response, advocates for a shift toward participatory and evidence-based policy processes that integrate scientific modeling, stakeholder knowledge, and iterative learning. These processes, when they are properly institutionalized, can improve the quality of policy design, enhance legitimacy, and promote adaptive governance in the face of uncertainty.

In sum, this chapter provides a theoretically grounded, empirically informed, and policy-relevant roadmap for catalyzing innovation in African agrifood systems. It highlights the critical role of public policy in shaping incentives, aligning investments, and enabling inclusive and climate-resilient transformation. The ultimate goal is not merely to improve yields or reduce hunger in the short term; rather, it is to foster a sustainable and equitable agrifood system in which science, technology, and innovation (STI) are leveraged as powerful tools for development in the post-Malabo era and beyond.

# *Typology of Technologies*

While new technologies offer the promise of shifting the production frontier, a key challenge remains: how to reduce technical inefficiencies through the widespread adoption and effective use of both conventional and innovative technologies. This section categorizes the relevant technologies into three broad groups, namely conventional agricultural, digital, and biological; it then maps them across the various components of the food system in order to examine their applicability, scalability, and potential for impact.

## Typology by technology domain

### *Conventional agricultural technologies*

Conventional agricultural technologies remain foundational to African agrifood systems. They include mechanization, commercial inputs (such as synthetic fertilizers, pesticides, and improved seeds), and irrigation systems. Mechanization, especially, has demonstrated potential to improve labor productivity and reduce drudgery, particularly in labor-constrained settings. Its widespread adoption, however, is limited by cost, infrastructure deficits, and fragmented landholdings. Evidence suggests that mechanization alone cannot close yield gaps unless it is accompanied by other inputs and extension services (Sheahan and Barrett 2017). In SSA, the use of improved seeds, fertilizers, and irrigation is often constrained by a combination of low affordability, limited awareness, and institutional bottlenecks. These constraints manifest through poor access to input markets, underdeveloped extension systems, and weak infrastructure. In regions like Tanzania, smallholder farmers have identified high input costs, lack of technical know-how, and marketing limitations as key barriers to the adoption of agricultural technologies, despite their recognized benefits. This underutilization of critical inputs directly contributes to the region's low productivity; promising results, however, have been shown to follow from targeted interventions that bundle inputs with credit and advisory services. A randomized control trial in Ghana (Mishra et al. 2023), for example, found that farmers were significantly more likely to adopt the use of fertilizer when credit was bundled with index insurance. This outcome highlights two key mechanisms: addressing liquidity constraints by improving access to credit and de-risking agricultural investment through insurance. This underscores how innovative financial mechanisms can crowd in the use of productivity-enhancing inputs, especially in risk-prone environments. These financial tools are an important complement to conventional technologies and need to be included in any holistic framework for agrifood transformation. Similarly, a study on wheat farmers in Sudan found that access to credit, quality seeds, and effective extension services were among the strongest predictors of improved technology adoption; this further underscores the importance of integrated institutional support mechanisms (Ibrahim et al. 2024). These findings collectively suggest that, alongside the provision of improved technology, addressing market and institutional failures is essential to driving inclusive and sustained agricultural transformation in the region.

### *Digital technologies*

Digital technologies present a unique opportunity for Africa to leapfrog traditional agricultural development pathways. Mobile platforms, blockchain, and AI are increasingly being applied in agrifood systems to address challenges across the value chain. Mobile platforms are particularly relevant in enabling market access, financial inclusion, and extension services; in addition to services such as e-wallets, they have been instrumental in connecting smallholder farmers to input suppliers, buyers, and insurance providers (Klerkx, Jakku, and Labarthe 2019). In Kenya, for example, the introduction of platforms such as M-Farm and DigiFarm has shown how digital solutions can bridge information asymmetries and improve incomes. Blockchain technologies are also gaining attention for their potential to enhance traceability and transparency in food systems. This is particularly crucial for export-oriented value chains such as coffee, cocoa, and horticulture, where quality assurance and certifications can significantly impact competitiveness. AI and big data analytics are also transforming predictive modeling for weather, pest outbreaks, and crop diseases. Both startups and international organizations are using satellite imagery and machine learning to develop early warning systems and optimize input use. These innovations offer high potential, but they also require enabling infrastructure such as reliable internet, data governance frameworks, and digital literacy. While digital technologies can shift the technological frontier, their diffusion is uneven and often limited by infrastructural and educational gaps, resulting in a persistent technology divide. Their success hinges on targeted public investments and on inclusive design that considers local socioeconomic realities. Where digital infrastructure is weak, combining mobile tools with social learning approaches such as group-based learning or lead-farmer models can enhance the diffusion of information and augment trust in new technologies. Studies show that digital platforms layered with social capital structures can accelerate adoption (Dougill et al. 2021).

### *Biological technologies*

Biological technologies are the most promising and transformative innovations for African agrifood systems; they include gene editing, biofortification, biofertilizers, aquaponics, and insect farming. One gene-editing technology is CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats), which allows scientists to precisely modify DNA sequences; it, along with others like it, has the potential to create climate-resilient crops that can withstand drought, pests, and diseases. Biofortified crops such as Vitamin A-enriched cassava and iron-rich beans can address micronutrient deficiencies at scale and are already being promoted in various African countries through programs such as HarvestPlus (Saltzman et al. 2013). Biofertilizers and biological pest control systems are gaining traction as sustainable alternatives to chemical inputs. These solutions can enhance soil health, reduce environmental and human health risks, and offer long-term cost savings for farmers. Innovations such as aquaponics and insect farming (for example, using black soldier fly larvae for animal feed) are part of a broader push toward circular and sustainable food production systems. These technologies are particularly attractive in urban and peri-urban settings, where land and water are limited. Finally, carbon farming and bioenergy production present opportunities for both climate mitigation and rural income generation. By sequestering carbon through soil management practices and biochar, farmers can potentially access carbon credit markets.

### *Technological innovations in food system components*

Technological innovations across the food system represent a critical dimension of agrifood systems transformation in Africa. Rather than being limited to production, technologies now serve an interconnected range of functions, including in food processing, storage, distribution, retailing, and consumption. Understanding how technologies vary across these segments is essential to identifying leverage points for systemic change and addressing the continent's persistent inefficiencies, such as postharvest loss, market exclusion, and poor dietary outcomes. A food systems approach allows us to map technology interventions, not only for their productivity impact but also for their roles in sustainability, nutrition, and equity.

### *Financial and social innovations*

Financial innovations such as index-based insurance, mobile credit platforms, and weather-triggered safety nets play a crucial role in de-risking smallholder production. These tools address liquidity constraints and production risks, thereby increasing the uptake of productivity-enhancing inputs such as fertilizer and improved seeds (Mishra et al. 2023). Similarly, social innovations—including farmer cooperatives, participatory extension models, and ICT-facilitated peer-learning networks—enhance trust, knowledge flows, and collective action, which are essential for scaling new technologies. For a broader conceptualization, these fall under the sociotechnical innovation bundles framework discussed by Barrett et al. (2022), which emphasizes the coevolution of technologies with social structures and institutions.

## Technologies across the agrifood system

Technological transformation in food systems often begins at the production stage, where a series of digital and biological tools are redefining traditional practices. Precision agriculture tools such as drones, satellite imaging, and GPS-guided machinery allow for site-specific input application, thus improving resource efficiency and productivity. These tools enable farmers to monitor crop health, detect pest infestations early, and apply water or fertilizer in targeted ways that significantly reduce input waste and increase yields (Gebbers and Adamchuk 2010). Climate-resilient crops, often developed through gene editing as well as traditional breeding methods, are increasingly central to sustainable agricultural production. These varieties are engineered to withstand stresses such as drought, salinity, and disease, allowing farmers to maintain productivity under changing climatic conditions. Artificial intelligence is also being deployed for predictive modeling of pest and disease outbreaks; for instance, machine learning models trained on satellite and weather data can forecast locust movements or fungal infestations, enabling proactive interventions rather than reactive measures (Kamilaris, Fonts, and Prenafeta-Boldú 2017). The integration of such tools, while still in their early phases, represents a foundational shift in how production challenges are being approached.

At the processing level, technologies play a key role in improving food quality, nutritional value, and marketability. Automation and robotics are increasingly being used for sorting, grading, and packaging, thereby reducing labor costs and ensuring uniformity in product standards. Such improvements are vital for gaining access to high-value export markets where compliance with stringent quality standards is nonnegotiable. One of the most impactful areas in food processing is biofortification, which involves enhancing the micronutrient content of staple crops such as maize, cassava, and sweet potatoes. Biofortified foods offer a scalable strategy for combating the hidden hunger of micronutrient deficiencies that affects millions across Africa. Programs like HarvestPlus have demonstrated that biofortified crops can improve nutritional outcomes, especially in rural populations where diet diversity is low (Saltzman et al. 2013). Functional food processing technologies that preserve or enhance the health benefits of food are also gaining ground. These include fermentation systems, nutrient retention equipment, and low-temperature drying. In many African countries, such technologies are being localized to small-scale, decentralized processing centers, thus creating rural employment while reducing losses.

Storage remains one of the most critical bottlenecks in African food systems. Poor storage infrastructure leads to an estimated loss of 30 to 40 percent of food postharvest, especially perishables such as fruits, vegetables, and dairy products. Low-cost but highly effective technological innovations, such as hermetic storage bags, can prevent oxygen and pests from degrading stored grains. Trials in countries such as Nigeria and Kenya have shown that using these bags can reduce postharvest insect infestation by up to 98 percent (Baoua et al. 2014). More advanced solutions, such as solar-powered cold chains, can also play a critical role in maintaining the quality of perishables. These systems offer off-grid refrigeration options for rural and peri-urban markets, dramatically reducing spoilage and expanding market access for fresh produce. The use of Internet of Things (IoT) devices for inventory monitoring is also becoming more common. These systems alert users in real time to storage conditions such as temperature and humidity fluctuations, allowing for timely interventions.

Improved distribution technologies are instrumental in overcoming the high transaction costs that have characterized African food markets. Blockchain technology, though still in its nascent stages, is being applied to improve traceability in food value chains. Cocoa and coffee cooperatives in Ghana and Ethiopia, for example, have piloted blockchain systems that allow consumers to verify the origin and quality of products, thus improving trust and potentially commanding higher prices (Kamilaris, Fonts, and Prenafeta-Boldú 2019). Digital e-market platforms are another powerful tool for reducing inefficiencies in food distribution. Platforms such as Twiga Foods in Kenya match farmers with retailers and manage logistics in real time, minimizing wastage and stabilizing prices. These systems reduce the number of intermediaries and allow smallholders to retain more value from their produce (Kithae and Munge 2025).

In the retailing segment, digital marketplaces and mobile payment platforms have democratized access for both urban and rural consumers. The proliferation of smartphones and mobile money services enables real-time transactions, dynamic pricing, and remote ordering. In Uganda and Tanzania, mobile-based agribusiness platforms such as AgroMall and FarmCrowdy provide end-to-end solutions that include procurement, financing, and sales. Such platforms are especially empowering for women and youth, who have historically been excluded from formal market systems. Gender-inclusive design, including features such as local language interfaces and microcredit facilities, further enhances their impact (Mehar, Mittal, and Prasad 2016). These technologies foster financial inclusion and enable greater participation in agrifood entrepreneurship.

At the consumption end of the agrifood system, technologies are helping shape healthier and more sustainable dietary patterns. Mobile apps that offer personalized nutrition guidance based on user profiles are increasingly popular. They promote dietary diversity, track food intake, and provide recipes based on local ingredients, all of which are vital in areas where the incidence of noncommunicable diseases is rising. Consumer awareness and accountability are enhanced by food-labeling technologies such as QR code systems that disclose nutritional information and sourcing practices. These digital tools not only support informed decision-making, but they also help consumers trace the origin and health value of products; this is particularly valued in markets where transparency is emerging as a key consumer demand. Research shows that placing QR codes on packaging significantly improves consumers' comprehension and confidence in food choices, enhances traceability, and strengthens trust in food systems (Rotsios et al. 2022). The loop between food production and environmental sustainability is meanwhile being closed by tools for reducing food waste, including insect farming, smart composters, and donation platforms.

## Implications

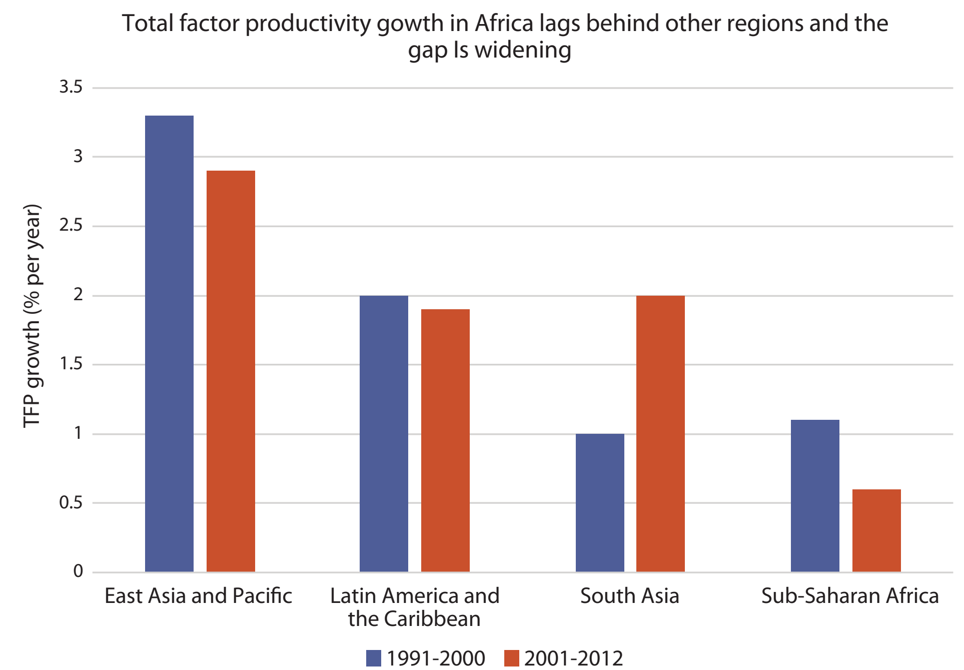
Each technology domain—conventional, digital, and biological—offers distinct but complementary pathways for transforming African agrifood systems. While conventional technologies address productivity, digital technologies improve efficiency and connectivity, and biological innovations enhance sustainability and climate resilience. Mapping these technologies across the food system reveals both gaps and synergies. Production technologies tend to receive the most attention, yet improvements in processing, storage, and distribution technologies are equally vital to system-wide transformation. Effective scaling requires integrating technical improvements and combining them with institutional and policy innovations. Ultimately, bridging the gap between current inefficiencies and the potential technological frontier is not merely a technical challenge, but also a political and social one. Strategic public investment, inclusive policies, and stakeholder coordination are essential to realizing the full benefits of agrifood technologies in Africa.

# *Historical Pathways of Innovation Policy*

Following the classical contribution of Johnston and Mellor (1961), increasing agricultural productivity stimulates economic growth and poverty reduction in several ways. Boosting agricultural productivity not only raises the incomes of farm households, which generally make up more than half the population in developing economies, but it also lowers food costs for the nonfarm population and promotes the development of agro-industry. This in turn promotes broader economic growth by stimulating demand for nonfarm goods and services. Higher productivity also frees up resources, such as labor, for the growth of other economic sectors. Economic growth, however, is not in itself a final goal; rather, it is one strategy toward sustainable development. A second challenge of promoting economic growth is achieving the kind of inclusivity that maximally contributes to the achievement of the Sustainable Development Goals (SDGs); this includes, for example, the reduction of poverty and undernourishment, the achievement of environmental goals around biodiversity, reduction of greenhouse gas (GHG) emissions, and increased resilience of the complete ecological, social and economic system.

Asia and Latin America have demonstrated the successful promotion of inclusive economic growth via increased agricultural productivity. Starting with the Green Revolution in the 1980s, significant improvements in agricultural production have been observed, driven mainly by increases in total factor productivity (TFP) and land-use intensification, while land inputs in Asian and Latin American countries have remained relatively constant (see Figure 2.1).

**FIGURE 2.1—GROWTH IN TOTAL FACTOR PRODUCTIVITY IN AGRICULTURE ACROSS CONTINENTS**



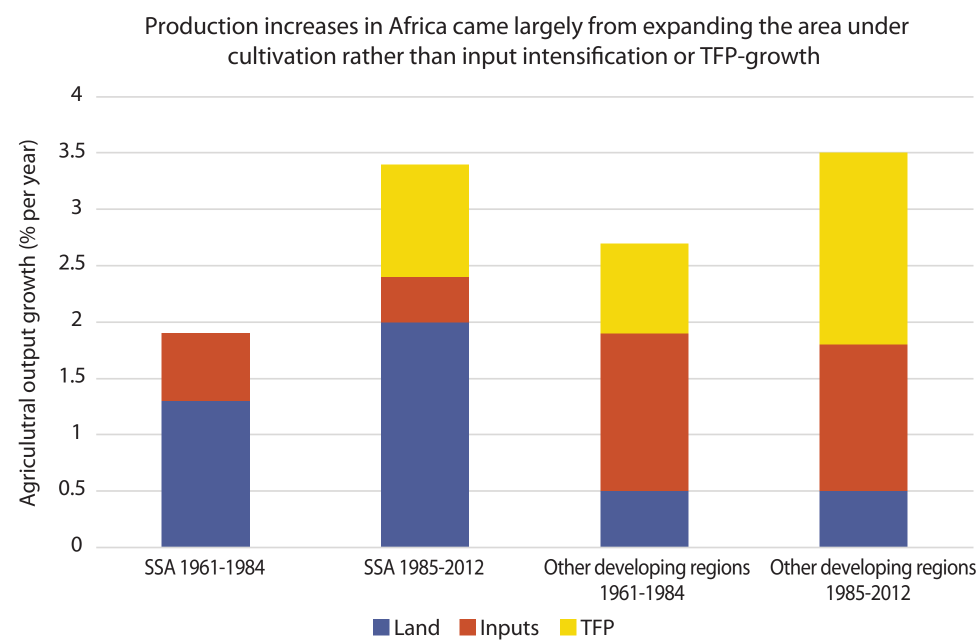

Source: Goyal and Nash (2017).

Induced agricultural productivity growth implied significant progress toward the achievement of the SDGs. Between 1990 and 2023, for example, poverty was reduced by 84 percent in Asia and by 76 percent in Latin America; thus, by 2024, with only 10 percent of Latin America's population living in extreme poverty and only 4 percent of Asia's, it can almost be claimed that poverty has been eliminated in these regions. In both regions, agricultural productivity growth and induced positive sustainable development have been driven by public investment in rural public goods in combination with better policies to strengthen markets, expand water access, and develop and adopt improved technologies. Such spending has been complemented by improvements in the policy environment, including trade and regulatory reforms; these have further incentivized producers and innovators to take advantage of public goods, thereby crowding in private investment.

In SSA as well, improving agricultural productivity has become an important strategy for reducing poverty, enhancing inclusive growth, and promoting structural transformation. Nearly two-thirds of the world's poor people live in SSA, and in 2018, more than 80 percent of Africa's poor lived in rural areas (Wollburg et al. 2023). In 2003, African heads of state committed themselves to increasing investment in agricultural productivity and rural development, and that commitment was enshrined in the Maputo Declaration on Agriculture and Food Security in Africa. Their commitment was echoed in the 2005 report of the UN Millennium Project, which called for at least a doubling of agricultural productivity in Africa as the key to reducing hunger and poverty. In the early 2000s, partly in response to these public commitments, spending on agricultural research rose steadily, and in the first 15 years of the new millennium, public sector research spending averaged over US$2 billion annually across SSA (Beintema and Stads 2017). Compared to Asia and Latin America, however, the significant success of agriculture-led inclusive growth was not yet observable in the region. One important reason for this has been that in SSA, in contrast to in other developing regions, agricultural growth is driven mainly by land expansion, while increases in TFP have played only a minor role (Goyal and Nash 2017) (see Figure 2.2).

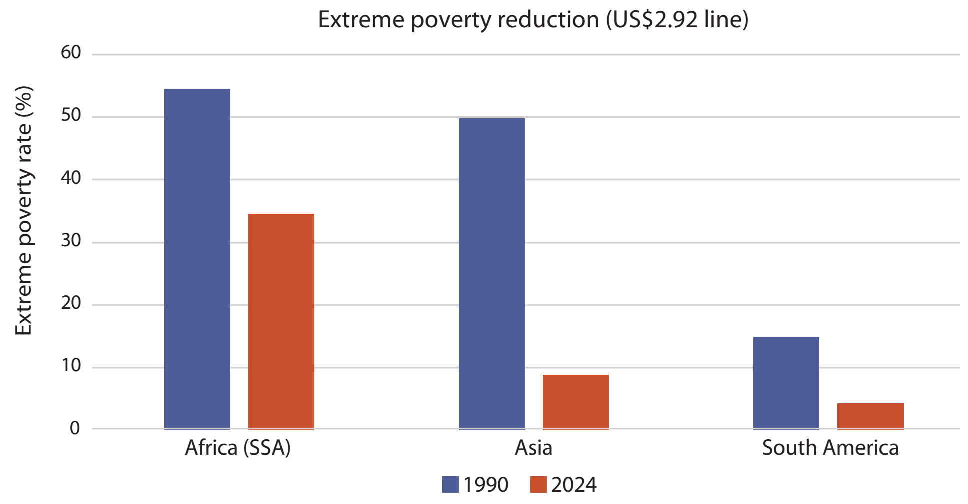
A microeconomic study was recently conducted that was based on a large farm panel survey of over 30,000 farms. It revealed that, between 2000 and 2019, TFP growth had been either stagnant or negative among small-scale farms (Wollburg et al. 2023). Since African agriculture, especially among rural populations living in poverty, is mainly composed of smallholder farms, this low productivity also implies limited progress on SDGs such as poverty and hunger reduction. Compared to developing countries in Asia and Latin America, SSA has lagged significantly in translating agricultural growth into broad-based development outcomes. As shown in Figures 2.3 and 2.4, poverty in Africa declined by only 37 percent between 1990 and 2024. Even in 2024, extreme poverty remained high, with 35 percent of the total population of SSA living below the poverty line of US$2.92 per day. Over the same period from

**FIGURE 2.2—SOURCES OF AGRICULTURAL PRODUCTIVITY GAINS ACROSS CONTINENTS**



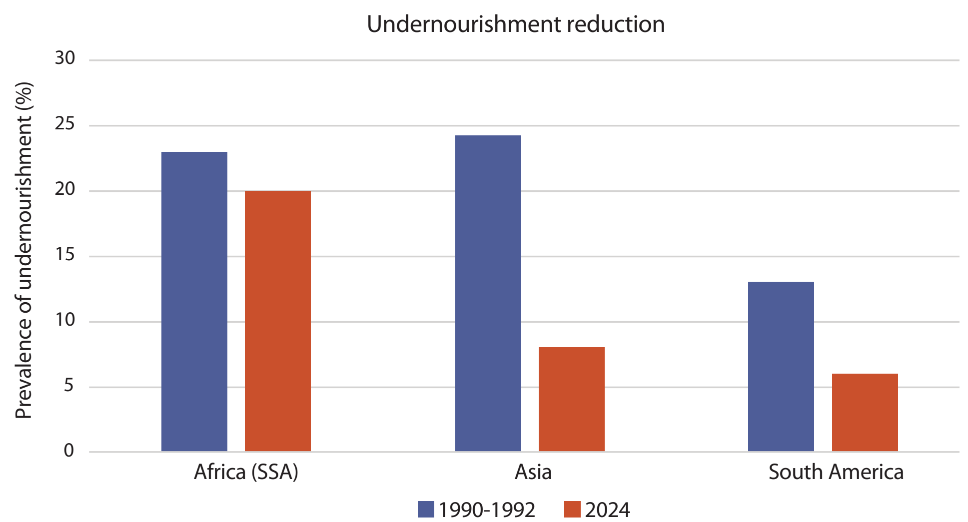

Source: Goyal and Nash 2017.
Note: SSA = Sub-Saharan Africa.

## FIGURE 2.3—REDUCTION IN EXTREME POVERTY ACROSS CONTINENTS




Source: Authors' own calculations, based on World Bank development indicators.

## FIGURE 2.4—REDUCTION IN UNDERNOURISHMENT ACROSS CONTINENTS




Source: Authors' own calculations, based on World Bank development indicators.

1990 to 2024, the percentage of the population experiencing hunger declined by only 3 percent, moving from 23 to 20 percent. In Asia and Latin America, in contrast, the prevalence of hunger declined by 67 and 54 percent, respectively; thus, with only 6 and 8 percent of those respective populations experiencing hunger, its imminent elimination there could almost be anticipated.

## Guiding questions for the chapter

While this chapter highlights critical pathways for moving the technology frontier in African agrifood systems, several strategic and interesting questions remain that merit further exploration by researchers, policymakers, and development actors. These include:

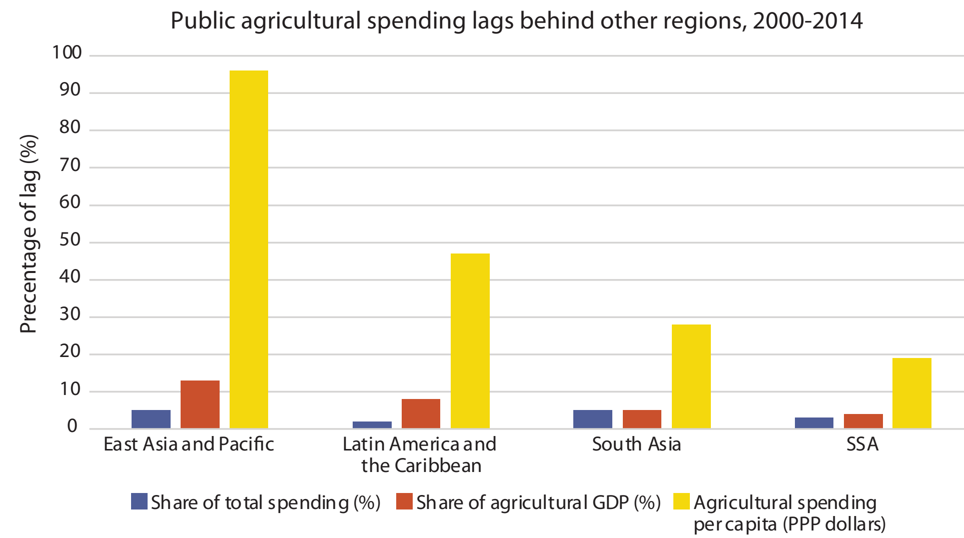
- Why is Africa lagging in the promotion of agricultural productivity and in generating inclusive, sustainable growth?
- What is the role of innovative technologies, digital farming, and biotechnology, vis-à-vis conventional agriculture, in promoting sustainable development in Africa?
- What policy design would successfully promote inclusive and sustainable growth in SSA?
- How can technological innovations be adapted and scaled across Africa's diverse agroecological and socioeconomic contexts to ensure equitable access and sustained adoption?
- What are the key institutional and governance barriers to the adoption and scaling of agrifood technology, and what reforms are needed to overcome these barriers in African agrifood systems?
- How can innovations be equitably tailored and scaled across diverse African contexts?
- What metrics and data systems are needed to track innovation adoption, scaling, and impact across the agrifood system?
- What roles should different actors (for example, the public and private sectors, development partners, and farmers) play in driving agrifood innovation systems?
- How can evidence-based and participatory policy processes be institutionalized under conditions of uncertainty?

## Why is Africa lagging behind?

That African governments invest too little in agriculture is clear from a comparison with the total spending on agriculture in successful Asian and Latin American countries. This is the case despite both the 2003 Maputo declaration and the 2014 Malabo declaration. As shown in Figure 2.5, between 2000 and 2014, African countries spent, on average, only US$19 per capita (in purchasing power parity, or PPP) on agriculture, compared to US$47 PPP per capita in South America and US$96 PPP per capita in East Asian countries. Even in other metrics, however, public agricultural spending in Africa has lagged behind that of other developing regions. Agricultural spending as a share of overall public spending (the metric used in the Maputo declaration) is substantially lower than in other regions, particularly East Asia and the Pacific and South Asia. According to yet another metric, public spending on agriculture as a share of agricultural GDP spending is also substantially lower in Africa than in other regions. As shown in Figure 2.6, these metrics did not change substantially under Malabo.

Increasing public spending on agriculture will be important, but it is not sufficient to induce agricultural growth and poverty reduction (Goyal and Nash (2017). Beyond the total amount spent, the allocation of spending is crucial, since different investment priorities and the related policy programs are differently effective in promoting inclusive economic growth (Henning et al. 2018, 2025). Many studies report that agricultural spending often yields low returns. This is largely because funds are directed toward initiatives and policies that have little—or even negative—impact on agricultural productivity. Benin (2015), for example, argues that the effectiveness of spending under the Maputo declaration was rather low, because spending by the Comprehensive Africa Agriculture Development Programme (CAADP) is focused on subsidy payments, which are not

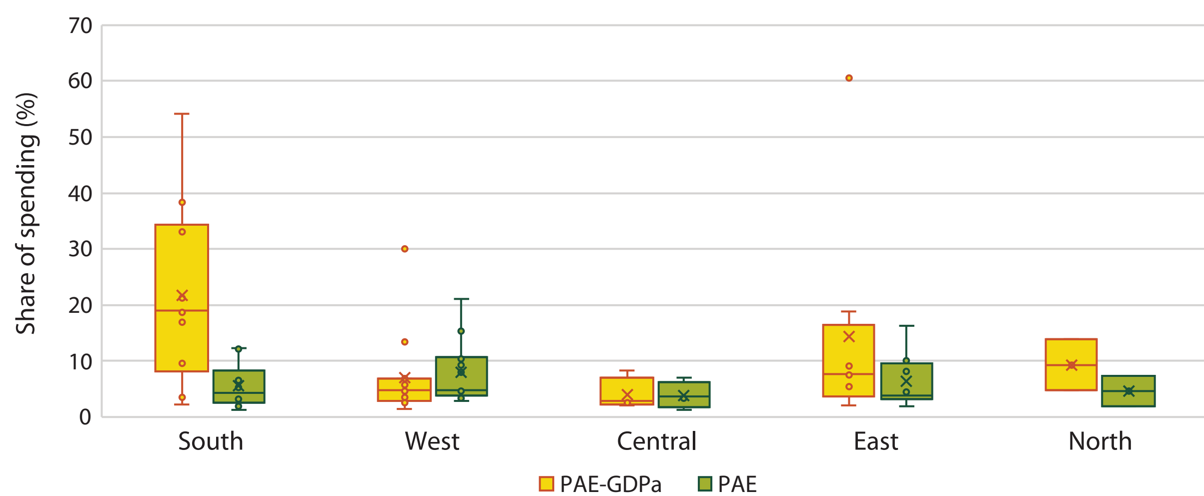
**FIGURE 2.5—PUBLIC SPENDING ON AGRICULTURE: AFRICA IS LAGGING BEHIND**




Source: Goyal and Nash (2017).

Note: PPP = purchasing power parity. SSA = Sub-Saharan Africa

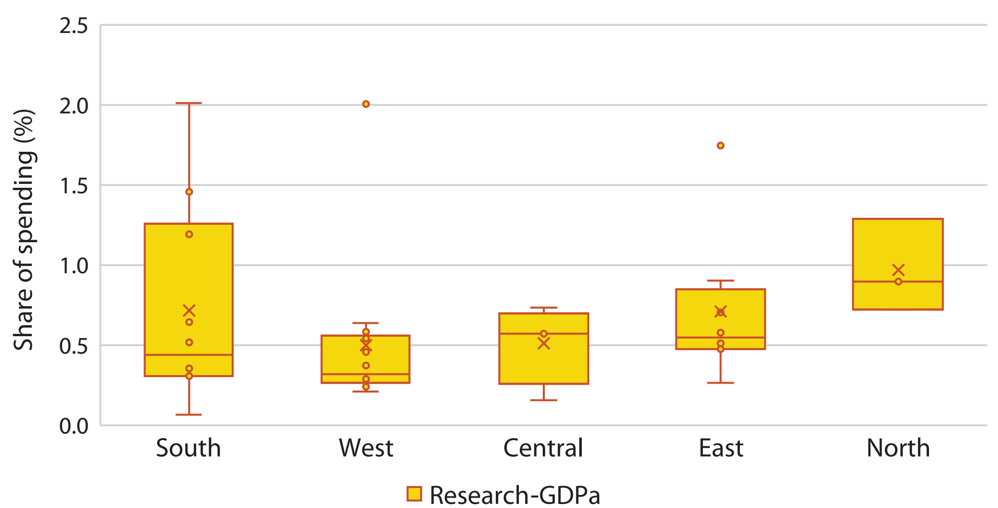
**FIGURE 2.6—SHARE OF PUBLIC SPENDING ON AGRICULTURE IN PERCENT OF TOTAL PUBLIC SPENDING AND IN PERCENT OF AGRICULTURAL GDP IN AFRICAN COUNTRIES**




Source: Henning et al. (2025).

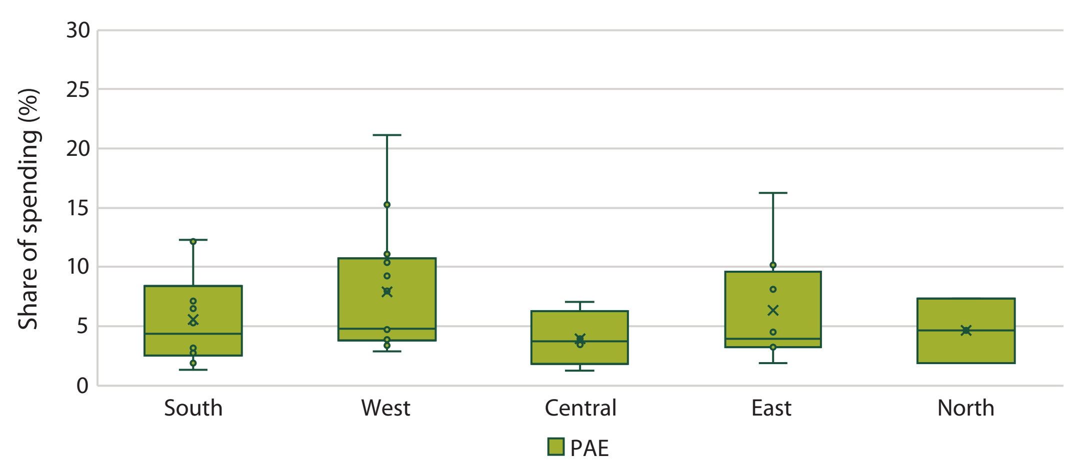
Note: PAE = share of public spending on agriculture in the total state budget, PAE_GDPa = share of public spending on agriculture in agricultural GDP.

FIGURE 2.7—OPTIMAL SHARE OF PUBLIC SPENDING ON RESEARCH IN AFRICAN COUNTRIES, IN PERCENTAGE OF AGRICULTURAL GDP




Source: Henning et al. (2025).
Note: Research-GDPa = share of public spending on agricultural research in agriculture GDP.

FIGURE 2.8—OPTIMAL SHARE OF PUBLIC SPENDING ON AGRICULTURE IN AFRICAN COUNTRIES, IN PERCENTAGE OF TOTAL PUBLIC SPENDING




Source: Henning et al. (2025).
Note: PAE = share of public spending on agriculture in the total state budget. Box plots show 50% and 95% confidence intervals.

productive in promoting inclusive agricultural growth (Goyal 2017). According to Benin (2015), spending on agricultural research and extension has a high impact on agricultural productivity and induced inclusive economic growth; however, the literature reports mixed results when measuring the effectiveness of specific public spending on agriculture in African countries. Henning et al. 2025, for example, estimated returns to public spending on agricultural research using an innovative approach that combined AI methods with Computable General Equilibrium (CGE) modeling; they applied metamodeling techniques using data from the Biennial Review of 38 African countries, collected under the Malabo declaration. In contrast to Benin (2015), results estimated by Henning et al. (2025) implied comparatively low returns on investment in agricultural research for many African countries, yet even R&D investments below the 1 percent benchmark in agricultural GDP turned out to be optimal for most African countries (see Figure 2.7). Estimates also show a high variance in the optimal amount of total public investment in agriculture; that is, there was support for neither the Mabuto benchmark of a 10 percent share of the total state budget nor for a common benchmark share of agricultural GDP (see Figures 2.7 and 2.8).

Ultimately, how public agricultural spending is allocated matters greatly. Not only does the effectiveness of individual programs depend on allocation decisions, but the optimal total budget itself is shaped by how funds are distributed across policies and activities. The more the actual allocation of public spending differs from the optimal, the lower the returns on total spending. Finally, given the analysis by Henning et al. (2025), there seems to be no generally optimal allocation of spending across activities; rather, optimal allocation appears to depend on country-specific structural conditions. This is clearly shown in Figure 2.8, which presents a region-by-region calculation of the optimal shares of total national budgets spent on agriculture across 38 African countries. Formulating public policies that promote sustainable economic growth is thus a rather complex technical task for African governments, as it requires a holistic understanding of the complex interactions and responses of the complete ecological-economic and social system.

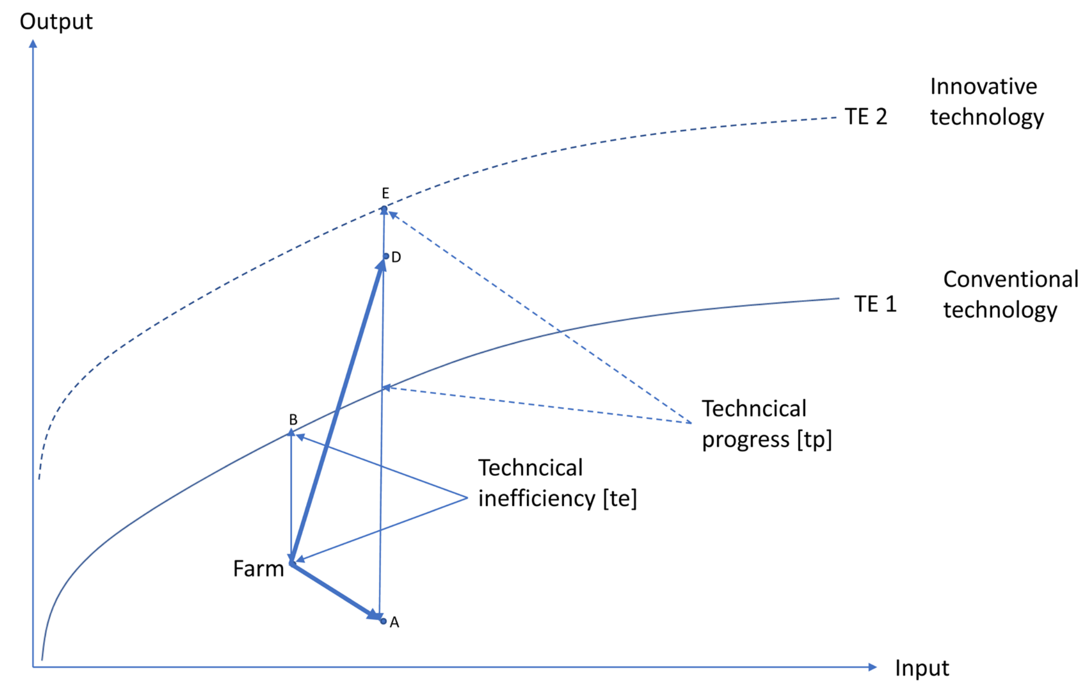
What is the role of digital farming and biotechnology vis-à-vis conventional agriculture in promoting sustainable development in Africa?

It is clear that Africa has a great potential to increase the productivity of conventional agriculture, thus inducing significant economic growth (Fuglie 2023; Ittersum 2010, 2025). Ittersum (2010, 2025), for example, demonstrates that gaps between actual and potential yields for rainfed cereal crops amount to between 40 and 60 percent of current realized yields. Microeconomic studies applying parametric or nonparametric stochastic frontier approaches also disentangle changes in TFP from technological progress and changes in technical efficiency; they report yield gaps in conventional agriculture of between 60 and 80 percent (see, for example, Wollburg et al. 2023; Djoumessi 2022). As can be seen from Figure 2.9, at a micro level, TFP can be divided into two distinct pathways. The first of these is technical progress, which corresponds to a shift in the production frontier, and the second shows changes in technical efficiency, corresponding to a change in the average distance of farmers from the production frontier. Hence, while technical progress (TP) corresponds to the invention of a new technology, a reduction in technical inefficiency corresponds to learning-by-doing effects. Empirical studies that estimate the total increase in TFP in African agriculture and that decompose it into increased technical efficiency (TE) and increased TP clearly imply that increases in TFP mainly correspond to an increase in TE, while TP played only a minor role. A study by Djoumessi (2022), for example, estimated a translog stochastic frontier analysis (SFA) function based on panel data for 23 African countries between 2000 and 2015; the results suggested that 80 percent of the estimated TFP increase corresponds to an increase in TE, while only 20 percent results from TP.

Furthermore, low productivity, especially on small-scale farms, results from high transaction costs; that is, limited access to input markets leads to low use of mineral fertilizers and improved seeds by small-scale farmers (see Guèdègbé and Doukkali 2018). Thus, although farmers are familiar with the most efficient frontier technologies, high transaction costs—implying high relative prices for advanced inputs—result in a situation where it is more profitable for farms to use the low-yield technology. Technically, this phenomenon is captured in a meta-frontier production function. As illustrated in Figure 2.10, high transaction costs force farmers to operate at an input location A, where the low-yield production frontier corresponds to the meta-frontier function; without transaction costs, however, farmers would operate at an input location B, where the innovative technology corresponds to the meta frontier. Low productivity thus ensues, even though farmers are technically efficient and yield potentials are much higher with the innovative technology than with the conventional technology.

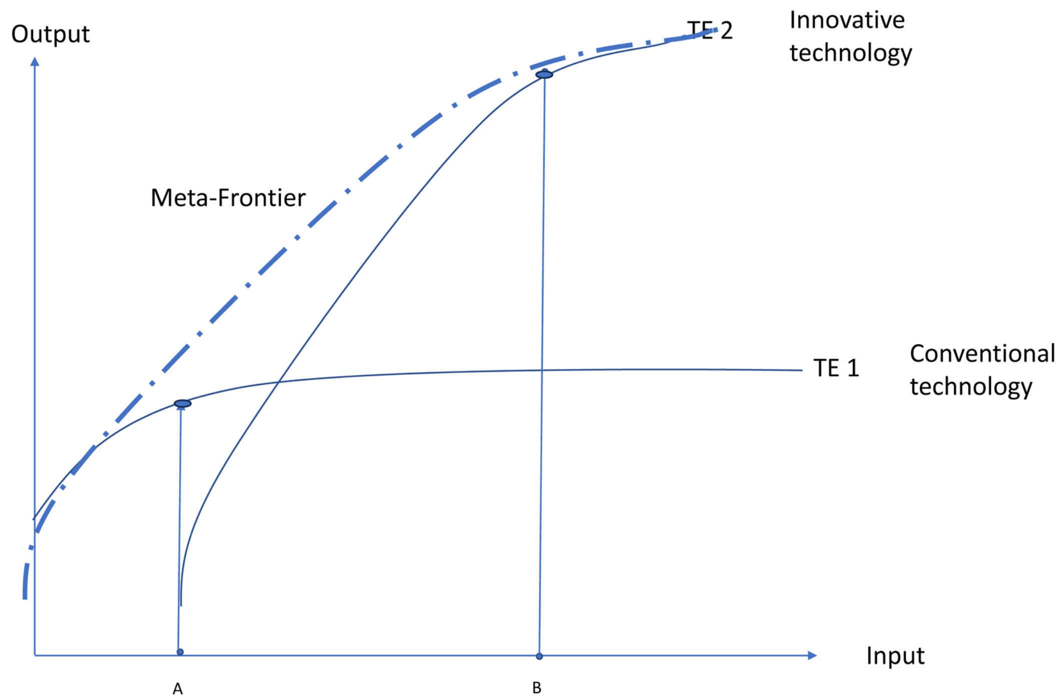
Finally, the economic efficiency of input use also depends on whether climate change is inducing higher temperatures, lower water availability, and

**FIGURE 2.9—ILLUSTRATION OF INNOVATIONS, TECHNICAL PROGRESS, AND TECHNICAL EFFICIENCY IN A PRODUCTION-FRONTIER FRAMEWORK**




Source: Authors.

**FIGURE 2.10—TRANSACTION COST AND TECHNOLOGY CHOICE IN A PRODUCTION FRONTIER FRAMEWORK**




Source: Authors.

that potential, however, requires first understanding the major bottlenecks at the farm level and the corresponding possible pathways of innovation-driven productivity growth, that is, technical progress, technical inefficiency, and reduced transaction costs. Biotechnology-based innovations contribute mainly to the tp pathway, while digital farming may contribute to the tp, te, and tc pathways. In the African context, for instance, technical progress enabled by digital technologies often centers on leapfrogging traditional methods; for example, combining precision farming with remote-sensing data and applying AI technologies to achieve more efficient production mechanisms. Digital platforms and information management systems, on the other hand, can enable more efficient learning via the exchange of information between individual farmers and between farmers and experts (digitalized extension services); this implies a reduction in technical inefficiency without necessarily shifting the production frontier. Especially in Africa, low productivity often results from small-scale farmers' limited access to input and output markets (see Wollburg et al. 2023). Innovative forms of e-governance, such as e-cooperatives or e-markets, on the other hand, correspond to organizational technical progress that implies a reduction of transaction costs; economic growth is thus promoted via a more efficient

more frequent extreme weather events, such as droughts and floods. Returns to more intensive production are, in that case, riskier; small-scale farmers without adequate access to insurance markets, in particular, experience a reduced economic incentive to use purchased inputs. Public investments in irrigation and land and water management infrastructure can thus promote the adaptation of efficient farm technologies (see Goyal and Nash 2017); moreover, biotechnology innovations such as genome editing provide climate-smart technologies that can compensate for the negative impacts of climate change.

Transaction costs also occur in output markets, that is, in international or domestic trade; this also acts to reduce the economic incentive of farmers and agribusinesses to apply the most productive technologies. There is thus great growth potential for both conventional and innovative agriculture. Reaping

factor allocation across farms. In this context, Barrett et al. (2022) emphasize the coevolution of technologies with social structures and institutions; for example, they interpret innovative organizational forms such as farmer cooperatives, participatory extension models, and ICT-facilitated peer-learning networks as social innovations that enhance trust, knowledge flow, and collective action. Technically, these organizational innovations can be best understood as formal and informal institutions that reduce transaction costs (see Henning, Henningsen, and Henningsen 2012; Mehar, Mittal, and Prasad 2016).

Beyond understanding which public policies most efficiently and effectively implement agricultural innovations at the farm level, it is also important to understand how economic benefits diffuse through the complete economy.

In a nutshell, innovation implemented at the farm level implies three major effects. The first of these is an increase in farm production, which implies (all else being equal) an increase in farm profits. The second effect of farm-level innovation is that increased agricultural supply at the sectoral level implies a decrease in supply prices. Third, an increase in productivity and overall farm production implies a change in factor demand, which in turn induces corresponding changes in factor prices. Depending on the type of innovation and the induced changes in output prices, total demand at the farm level can be increased or decreased for different factors. Induced input and output price changes have economywide spillover effects in other sectors. To understand the impact of policies, governments must understand the complete set of responses that occur in the economic system at the micro, meso, and macro levels. A successful promotion of TP at the micro level, for example, may induce structural adaptation at the meso or macro level that then induces counterintuitive impacts. A prominent example is Cochrane's technology treadmill theory, which implies that realization of TP in the agriculture sector can, in fact, reduce farm profits (Cochrane 1958). The logic behind Cochrane's theory is that TP induces an increase in supply, which then: 1) induces a disproportional reduction in farmgate prices; this then, 2) induces an increase in input prices due to higher demand, or 3) causes an increase in fixed costs due to the required investments in new capital goods such as machinery. Engel's law of demand is another example. It states that, in a growing economy, the relative prices for agricultural goods compared to non-agricultural goods decrease, and that this implies that, in a growing economy, the share of agriculture in total factor demand and in total GDP decreases. Agriculture's decreased share in a growing economy is a logical consequence of Engel's law of demand since, given the greater income elasticities for non-food expenditures, higher per capita incomes would entail a reduced relative expenditure on food. Interestingly, the more that technical progress in the agriculture sector exceeds that in the non-agriculture, the larger will be the induced decrease in relative prices and the decline in agriculture's share of GDP. Changes in relative output prices imply a reallocation of factors from the agriculture to the non-agriculture sector. If factor markets are plagued by high transaction costs, however, this reallocation is imperfect; this implies an oversupply of factors in agriculture and comparatively low farm incomes. Thus, promoting TP in the agriculture sector—especially for staple foods with low price and income elasticities—often induces lower and not (!) higher farm incomes, especially for small-scale farmers. One example of the unexpected policy impacts of promoting agricultural productivity is Malawi's Farm Input Subsidy Programme (FISP). Government vouchers for seed and fertilizer distributed as part of FISP significantly increased the supply of maize; the additional supply, however, caused a decline in farmgate prices that decreased the production gains from additional fertilizer use, especially for small-scale farmers (Diao et al. 2013). In a similar scenario, cotton production in West and Central Africa increased almost tenfold from 1970 to 1988; however, the increased supply induced significant local price decreases and thus lower farm profits (Bassett 2014). In sum, a simple Computable General Equilibrium (CGE) simulation demonstrates that a decline of total GDP in the agriculture sector results from increased TP in agriculture when income elasticities for agriculture commodities are sufficiently small (see Meng, Mei, and Fan 2026).

# *The Political Economy of Agrifood System Innovations*

## Theoretical framework

In this section, we develop a political economy model to better understand why most African governments failed to formulate development policies that functioned to get their countries out of poverty and hunger. Most political economy studies focus on biased political incentives as an explanation of low political performance (see the literature overview by Binswanger et al. 1997). In this chapter, in contrast, we focus on a second source of policy failure, which is the lack of adequate political knowledge.

Biased political incentives result from asymmetric lobbying activities (Grossman 1994) or biased voter behavior (Bardhan and Mookherjee 2002). Persson and Tabellini (2000) emphasize the role of formal constitutional rules as determinants of politicians' incentives for choosing inefficient policies. In addition to biased incentives, a lack of adequate political knowledge has been considered as an explanation for the poor political performance of countries. Existing studies, however, focus on biased voter beliefs; Beilhartz and Gersbach (2004), Bischoff and Siemers (2013), and Caplan (2007), for example, emphasize that the main determinant of inefficient policy choices is biased voter beliefs about policy impacts. Voter beliefs are defined as simplified mental models of the actual complex relationships between policy instruments and induced policy outcomes. The work of Caplan is highly recognized in the public choice literature, as he collects an impressive amount of evidence for persistently biased voter beliefs. Based on his empirical findings, Caplan draws a rather pessimistic conclusion: democratic mechanisms of preference aggregation naturally lead to inefficient policy choices.

From the perspective of the final governmental choice, however, biased voter beliefs translate into the biased political incentives of elected political agents. In contrast to existing literature, this chapter focuses on the politicians and lobbyists who make the final policy choices and who may also fail to fully understand the complex relationship between policy instruments and desired policy outcomes. Lack of political knowledge—that is, biased policy beliefs—is thus another important cause of policy failure beyond political incentive problems. In a dynamic context, explaining the persistence of a lack of political knowledge requires further explanation of the reasons why policy learning fails. In response to persistent policy failure in many developing countries, participatory and evidence-based political processes are increasingly being promoted as an omnipotent tool/mechanism for guaranteeing unbiased political incentives for political agents, and for allowing the full use of all available political knowledge at both the academic and practical levels. In practice, however, designing such ideal-typical policy processes is challenging (see Henning and Hedtrich 2018).

To analyze the political economy of innovation policies, we define $x$ as a vector of relevant public policies that impact innovation and induce economic growth. We define $z$ as a vector representing the status of relevant SDGs such as poverty reduction, food security, and GHG emissions. To abstract from any political incentive problems, let $S(z)$ denote a society's evaluation of progress toward these SDGs. Seeking to maximize political support, the government aims to implement public policies that increase $S(z)$.

We capture policy impact via the political technology, $T(x,z)$. The latter determines the status of SGDs, $z$, to be achieved by implementing public policy $x$. If the political technology were known, policy choice would become a simple matter of maximizing political support, that is,

$$Max \quad S(z) \quad s.t. \quad T(z,x)=0 \tag{1}$$

A problem in real-world politics, however, is that understanding the impacts of innovation policies is rather complex. Analytically, the intervention logic of innovation policies can be disentangled into two components: the first being the impact of economic growth on the achievement of the different SDGs, and the second being the generation of economic growth through public policies, $x$. The first component refers to the growth–goal relationship and the second to the policy–growth relationship (Ziesmer et al. 2023).

The growth–goal relationship corresponds to economywide responses to economic growth. Economic growth, for example, implies an increase in supply as well as in factor demand. A growth in factor demand induces higher household incomes and higher commodity demand. Commodity prices and factor prices change in response to relative demand and supply; this, in turn, determines a new equilibrium on commodity and factor markets. At the micro level, a change in household income implies a change in household demand. Assuming that a single household is representative of overall economic growth, an increase in household income implies an increase in consumption. Economic growth thus further implies a reduction in poverty and undernourishment; it may, however, also have negative impacts, such as inducing higher GHG emissions. Heterogeneity among household incomes may also result in households being affected differently, depending on their embeddedness in the economy. At the macro level, therefore, economic growth may also mainly benefit the rich while the real incomes of the poor decrease; this may imply that the latter, in fact, experience an increase in poverty and undernourishment. The distributional impact of economic growth is also significantly influenced by the sector in which it occurs. Growth in agriculture, for instance, tends to boost rural household incomes, while expansion in non-agriculture sectors may benefit urban populations more.

The amount of GHG emissions also differs significantly depending on whether growth occurs in the agriculture or non-agriculture sectors. In this context, an inclusive growth strategy looks for policies that promote economic growth in sectors where it induces increased incomes and consumption among poor households.

Policy–growth relationships are the second component of the intervention logic of innovation policies. This refers to the generation of economic growth through public policies, which implies the implementation of a mix of public policies, $x_i \in x$, that are specifically aimed at the efficient promotion of economic growth in sectors that have a maximal positive impact on SDG development.

To better understand public policy choices, we disentangle the political technology into a growth–goal component, $z=G(\beta)$, and a policy–growth component, $\beta=H(x)$:

$$T(z,x) \equiv 0 \quad \Leftrightarrow \quad z=G(H(x))\text{” and “}\beta=H(x) \tag{2}$$

Finally, policy choices are constrained by real-world politics; public expenditures under the CAADP, for example, cannot exceed a limited total budget.

Recent Nobel-recognized work in innovation economics by Aghion, Mokyr, and Howitt offers valuable insights for understanding these policy trade-offs. Their dynamic framework highlights that innovation generates both growth and temporary inequality through the process of creative destruction—where new technologies render old ones obsolete. Hence, policy optimization must balance the promotion of innovation with mechanisms that manage adjustment costs and distribute innovation gains inclusively. For Africa, this means integrating dynamic policy learning—where governments continuously refine interventions based on evidence and feedback from innovators, farmers, and markets—into the very architecture of agricultural policy design.

If we let $\bar{B}$ denote the total amount of public budget resources available for CAADP policies, then optimal policy choices result from the following maximization:

$$\begin{aligned} &Max \quad S(z) \\ &s.t. \\ &z = G(\beta) \\ &\beta = H(x) \\ &\sum_i X_i \leq \bar{B} \end{aligned} \tag{3}$$

Optimal allocation of CAADP expenditures across different public policy programs thus result from the first order conditions (FOCs):

$$\nabla_z S \; dG_\beta \; \nabla_x H = e, \tag{4}$$

where $\nabla_z S$ and $\nabla_x H$ denote the gradient vectors of $S$ and $H$, respectively; $dG_\beta$ is the Jacobian matrix of $G$, and $e$ is the unit vector.

To facilitate interpretation of the FOCs, we define the following cost functions. First, we define $C^z\ (z^0)$ as the minimal budget expenditures that are required to achieve the SDG outcome levels $z^0$.That is,

$$\begin{aligned} &C^z(z^o) = \min_x \sum_i X_i \\ &s.t. \\ &z^o = G(\beta) \\ &\beta = H(x) \end{aligned} \tag{5}$$

Second, we define $C^\beta\ (\beta^0)$ as the minimal budget expenditures that are required to achieve the economic growth levels $\beta^0$:

$$\begin{aligned} &C^\beta(\beta^o) = \min_x \sum_i X_i \\ &s.t. \\ &\beta^o = H(x) \end{aligned} \qquad 6)$$

Substituting the defined cost functions into the FOCs and defining $\Psi=(\Psi\_1,\ldots,\Psi\_k,\ldots,\Psi\_n)= {}^1\!/_\lambda\, \nabla_z S$ as the vector of shadow prices of SDGs (where λ denotes the Lagrange multiplier of budget constraint) [1] implies the following FOCs:

$$\Psi_k - \frac{\partial C^z}{\partial Z_k} = 0 \tag{7}$$

$$\sum_k \Psi_k \frac{\partial G_k}{\partial \beta_s} - \frac{\partial C^\beta}{\partial \beta_s} = 0 \tag{8}$$

Further, we define $\varrho_s = \sum_k \Psi_k \frac{\partial G_k}{\partial \beta_s}$ as the shadow price of economic growth in a sector s, that is, as the marginal value of sustainability achieved by a unit of economic growth in sector *s*. The last term, $\frac{\partial C^\beta}{\partial \beta_s}$ , corresponds to the marginal budget required to generate economic growth in sector *s*.

Accordingly, we can define key sectors as the marginal value of sustainability that is generated by investing an additional budget unit into promoting growth in a sector *s*:

$$\xi_s = \frac{\varrho_s}{\frac{\partial C^\beta}{\partial \beta_s}} \tag{9}$$

1 Please note that political incentive biases would be captured by "biased" shadow prices; that is, actual political processes lead to different shadow prices when compared to an ideal-typical democratic interest mediation.

### *Categorizing policies by innovation pathways*

For a better understanding of policy impacts, it is helpful to categorize public policies into distinct priority areas that align with specific innovation pathways. As described in the previous subsection, economic growth can result from different pathways, that is, from technological progress (TP), increased technical efficiency (TE), or reduced transaction costs (TC). Categorization of policies into priority areas allows a clear identification of which policies correspond to the intended innovation pathways. Generation of innovations focusing on the TP pathway, for example, occurs in the science and knowledge system, while policies focusing on adaptation of innovative technologies by individual enterprises at the micro level correspond to public policies that target agricultural extension services. As explained above, economic growth may also be induced by innovations triggered by lower transaction costs; furthermore, public investments in technical infrastructure or in the public management of natural resources such as land and water can be defined as policy priorities aligned with the transaction cost pathway.

Categorization of policies into policy priorities also allows a clear identification of which policies influence which types of innovation (technological, organizational, institutional, social). Policies that promote, for example, an innovative organization of small-scale farms, such as new forms of cooperatives, imply the increased access of small-scale farmers to input and output markets; this can be an important pathway to economic growth via reduced transaction costs.

Depending on a country's specific economic and demographic structure, different pathways are differently effective in promoting inclusive economic growth. Categorization of policies and mapping of policies to pathways thus enable policy analysts to:

- Understand the mechanisms of impact along innovation pathways
- Identify synergies and trade-offs across policies
- Design policy mixes that combine complementary instruments in order to promote inclusive growth most efficiently

For each policy priority, there also exist alternative policy programs for promoting a pathway. To increase technology adaptation, for example, capital investments or input use can be subsidized; alternatively, farmer training can be provided, or public investments in extension services can be undertaken. Moreover, for each policy program, there are alternative implementation strategies and mechanisms. Subsidy payments, for example, can be targeted to small-scale farms or to young or female farmers; public investments in research can be focused on a central national university, or money can be allocated across a larger set of regional research centers. Public investment can also be focused on equipment and buildings or, alternatively, on staffing and human capital.

To integrate policy categorization into our formal policy analysis, we assume the following nested structure of public policies. An upper nest corresponds to different policy priorities, where each priority focuses on a specific innovation pathway. For each policy priority, a second nest of policy programs is defined, where each policy program focuses on a specific aspect of the policy priority. At a third stage, for each policy program, a second, different nest of implementation mechanisms is defined. For notational convenience, we define the index $I$ to denote the upper nest of policy priorities, while the index $i \in I$ denotes the corresponding second nest of policy programs subordinated to each policy priority $I$. Finally, we denote $\iota_i \in i$ as an index of alternative mechanisms that are available for the implementation of a specific policy program, $i$, at a third stage.

The nested structure of public policies is reflected in a corresponding separable policy impact function:

$$H(x)=H(x_I\,(x_i\,(x_{\iota i}\,))), \tag{10}$$

where $X_I$ denotes public spending on the policy priority, $I$, while $X_i$ denotes spending on the policy program defined within the priority, $i \in I$. Finally, $X_{\iota i}$ denotes public spending on a specific implementation mechanism, $\iota_i \in i$, for the policy program $i$. It holds that: $X_I = \sum_{i \in I} X_i = \sum_{i \in I} \sum_{\iota_i \in i} X_{\iota i}$.

We further assume that, at each stage, policy impact functions are linear and homogeneous, that is:

$$H(x_I) = \theta(\mu_I\,\theta_I\,(\mu_i\,\theta_i\,(\mu_{\iota i}))), \tag{11}$$

where $\mu_I = \frac{X_I}{\sum_I X_I}$, $\mu_i = \frac{X_i}{\sum_{i \in I} X_i}$ $\mu_{\iota_i} = \frac{X_{\iota_i}}{\sum_{\iota_i \in i} X_{\iota_i}}$

$\mu_I$ is the share of spending on policy priority $I$ of total public spending. $\mu_i = X_i / X_I$ is the share spent on the policy program $i \in I$ within policy priority $I$. $\mu_{\iota i}$ is the share of spending allocated to the implementation mechanism $\iota_i$ for policy program $i$.

Given the nested structure of the policy impact function, it follows that one can empirically estimate the first stage on the basis of aggregated budget allocations across priorities $I$, where the identified effectiveness of aggregated budget allocation depends on the unobserved allocation across policy programs and implementation mechanisms within a policy priority, $\theta^I$ and $\theta^i, \forall i \in I$.

For simplicity, we will limit our formal analysis to the top nest of public spending, that is, the first stage of a multi-stage budget process that allocates spending across policy priorities. Then, first-order conditions of the maximization in eq. ( [eq:1]) above result as:

$$\sum_s \varrho_s \frac{\partial H_s}{\partial X_I} \theta^I = 1, \qquad (12)$$

where $\frac{\partial H_s}{\partial X_I} \theta^I$ corresponds to the marginal increase of economic growth in sector $s$ induced by one additional unit of spending on policy priority $I$. The latter can also be defined as the marginal productivity of spending on policy priority $I$ in increasing economic growth in sector $s$. Accordingly, we define $\varphi_I = \sum_s \varrho_s \frac{\partial H_s}{\partial X_I} \theta^I$ as the shadow price of policy priority $I$, since the latter corresponds to the marginal benefit of additional sustainability achieved via an additional unit of public spending on policy priority $I$. Basically, it follows from the FOCs that allocation of public spending across policy priorities is optimal when, for all policy priorities, marginal benefits equal the marginal costs of spending.

To understand the marginal benefits of public investments in different policy priority areas, however, a government needs to know the shadow prices of growth induced in different economic sectors $\varrho_s$, as well as the effectiveness of public spending allocations across policy programs and implementation mechanisms within each priority, $\theta_I$ and $\theta_i$, respectively. In particular, as explained above, the shadow prices of economic growth, $\varrho_s$, depend on the shadow prices of different SDGs, $\Psi$, and the marginal effectiveness of economic growth in a sector $s$ on the development of different SDGs.

Overall, to be able to allocate public spending optimally across policy priorities and related policy programs and implementation mechanisms, politicians need to fully understand the rather complex intervention logic and pathways of innovations. To that end, they should:

- Identify the **key sectors**, that is, the sectors with the highest inclusive growth potential, as encapsulated in sectoral shadow prices, $\varrho_s$. It is interesting, for example, to understand the relative extent to which the different agriculture sectors (that is, food crops, export crops, livestock, and fisheries), the agribusiness sector, and the non-agriculture sectors are key to promoting inclusive, sustainable growth in African countries.
- Identify the **key pathways** for promoting sustainable growth in key sectors, that is, increasing technical progress (TP pathway), increasing technical efficiency (TE pathway), or reducing transaction costs (TC pathway).
- Identify the most effective **key policy priorities** that are aligned with the most effective innovation pathways, that is, the policy priorities with the highest shadow prices, $\varphi_I$. An example of a relevant policy priority is public spending on research and extension services (R&E) that align mainly with the TP and TE pathways, which determine the generation and dissemination of knowledge. Investments in technical infrastructure (TI) and in public management of natural resources (NR), such as water and land, are also prominent policy priorities aligned to the TC pathway. Public spending on farm management (FM)—including promotion of the adaptation of innovative technologies—is a policy priority that is aligned with the TE pathway. Spending on farm management may also include expenditures that promote organizational innovations. This may include new ways to coordinate the small-scale farm sector, such as e-cooperatives; this corresponds to the TC pathway, increasing the access of small-scale farmers to credit and insurance and to input and output markets.
- Identify for each policy priority, $I$, the most efficient budget allocation across policy programs and implementation mechanisms, that is, **maximize efficiency**, $\theta^I$. The FM policy priority, for example, could include programs that focus on subsidization of inputs, as well as, alternatively, policy programs that are focused on training farmers to increase their knowledge and awareness regarding new innovative technologies.

As already explained above, while innovations in biotechnology play a major role in the TP pathway, digital farming can also play an important role in the TP, TE, and TC pathways. Promotion of e-cooperatives, for example, may not only increase small-scale farmers' technological knowledge; it may also improve their access to inputs such as fertilizer, credit, and insurance markets, as well as to output markets, which thus also relates to the TC pathway.

## Designing efficient governance systems

### *Institutional frameworks, regulatory actions, and capacity-building investments*

The successful implementation and impact of agrifood system innovations in Africa depend not only on their technical robustness but also on the broader institutional and governance ecosystems that enable their uptake. These ecosystems include national policies, regulatory frameworks, education and research systems, financial institutions, and infrastructure. Without the alignment of these elements, even the most promising innovations can fail to take root or generate their intended impacts. Understanding the interplay between technology, institutions, and capacity is crucial for fostering transformative change in African agrifood systems. A key determinant of technology adoption lies in the strength and clarity of national and regional policy frameworks. Policies that secure intellectual property (IP) rights, enforce data privacy standards, and ensure biosafety regulation provide a critical foundation for fostering innovation. When these frameworks are weak or fragmented, private sector actors often face too much risk to invest in research and development or to introduce innovations into the market. Diao et al. (2013), for example, argue that while increasing public investment in agriculture is essential, it must be coupled with policies that incentivize innovation, including regulatory support for agricultural inputs, land tenure security, and the integration of private sector actors into national innovation systems.

Equally important is the role of institutional governance in facilitating technology development and adoption. Agricultural research institutes, extension systems, and universities serve as key intermediaries between global knowledge and local practice; however, these institutions often face challenges such as bureaucratic inertia, insufficient funding, and limited responsiveness to farmer needs. In response, reforms have been proposed to reposition tertiary agricultural education institutions as innovation hubs. Ochola et al. (2010) highlight the need for African universities to adopt a systems-oriented approach that aligns curricula and research with national development priorities. This includes fostering partnerships with policymakers, the private sector, and farmer organizations to co-create demand-driven innovations. In this process, building the capacity of both humans and infrastructure is indispensable. Beyond formal education, it involves creating platforms for continuous learning, farmer training, and knowledge exchange. Agricultural innovation in Africa remains constrained by low levels of education, poor access to financial services, and inadequate physical infrastructure, such as roads, electricity, and internet connectivity. Addressing these constraints requires sustained public investment and donor coordination to build local technology capabilities that are socially and ecologically appropriate. Despite progress in these areas, persistent challenges hinder widespread adoption. Many African countries operate under disjointed and overlapping regulatory systems, leading to inefficiencies and uncertainty in the deployment of new technologies. Innovation can be stalled, for instance, by delayed regulatory approval for genetically modified organisms (GMOs) or by inconsistencies in digital agriculture data protocols. Similarly, a lack of harmonized regional standards for seed certification or agricultural inputs reduces the scalability of innovations across borders, impeding the potential for economies of scale. Technology adoption is also often uneven, with marginalized groups facing barriers to access, especially women, youth, and smallholders in remote areas. Ensuring inclusive infrastructure and support services is therefore a necessary condition for equitable technology uptake. This includes gender-sensitive extension services, localized financing models, and access to ICT tools in rural areas.

### *Fundamental model uncertainty, policy beliefs, and the role of participatory policy processes*

A key challenge in formulating and implementing effective policies to promote sustainable, inclusive growth is that understanding intervention logics and innovation pathways is complex; policy impacts can also be imperfectly observed in real-world politics. The most effective policymaking processes are thus now considered to be evidence-based, that is, involving the integration of scientific knowledge into political decision-making. A scientific understanding of the impact of public policies on sustainable inclusive growth corresponds to economic modeling frameworks that integrate ecological and economic models; an example of this is the Computable General Political Economy (CGPE) approach (see Henning, Badiane, and Krampe 2018; Henning, Tankari, and Ziesmer 2025; Ziesmer et al. 2023; Ziesmer 2024). Even science cannot deliver perfect knowledge, as it is plagued by fundamental model uncertainty (Manski 2011). The latter implies that a set of alternative models, $m \in M$, exists that have different growth–goal and policy–growth relationships. It further implies that, based on existing data and information, it is impossible to draw perfect statistical inferences about which model best captures the true data-generating process in a specific country. Accordingly, in order to make a rational policy decision, a politician must form beliefs to derive an optimal public budget allocation that maximizes expected political support; that is, a probability distribution, $p^M=(P_1,\ldots,P_m,\ldots,P_{|M|})$, must be attached across a selected subset of models, $m \in M$:

$$
\begin{aligned}
&Max \quad \sum_m P_m\, S(z^m) \cong \quad \sum_m \Psi^m\, z^m \\
&s.t. \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (13)\\
&z^m = G^m(\beta^m)\\
&C^{\beta^m}(x, \theta(\mu)) \leq \bar{B}
\end{aligned}
$$

In real-world politics, decision-makers do not comprehensively understand how the different SDGs are evaluated by their constituency; that is, they are uncertain about the shadow prices of the SDGs, $\Psi$. Furthermore, real-world decision-makers are fundamentally uncertain regarding growth–goal relationships—that is, $G(\beta)$, the optimal policy mix $\mu$, and the scale $\bar{B}$—that will generate economic growth most efficiently and effectively. To deal with these uncertainties, practical politicians often form naive beliefs; that is, they apply simple heuristics and narratives to mimic policy impacts. Moreover, to reduce complexity, politicians generally tend to focus on only one model when forming their beliefs, ignoring all alternative models (Manski 2011).

Compared to policy impacts that are derived from scientific models and that explicitly take fundamental model uncertainty into account, naive policy beliefs are often biased and thus lead to rather inefficient and ineffective policy choices.

An example of this can be seen in the context of implementing the Kampala declaration, which aimed to realize a sustainable food system transformation that promoted inclusive growth. There, politicians often entertained policy programs that promoted the reduction of food waste, especially at the postharvest stage; this was considered to be an appropriate strategy for increasing food production and simultaneously increasing farm incomes. Economic modeling, however, indicates that while the reduction of food waste at the production stage (for example, at the farm level) simultaneously benefits both rural and urban poor households, this does not apply to reducing food waste at the postharvest stage. The latter, instead, reduces the processing industry's demand for raw agricultural commodities, which mainly benefits urban consumers while causing a decline in farm prices and profits.

Moreover, even if technical progress is directly realized in the agriculture sector, economywide responses to technical progress may cause a decline in farm profits if farmgate prices drop in response to increased farm production—a phenomenon that is well known in the economic literature as Cochrane's technology treadmill theory.

Simple heuristics and beliefs applied by politicians to mimic policy impacts are thus often biased compared to policy impacts that are derived from scientific models. Accordingly, fundamental model uncertainty calls for political decision-making processes that are institutionally designed. This will allow for: 1) policy planning that is based on the aggregation of all available information in a society, which will promote policy learning; 2) advanced planning that is based on large-scale political experiments, for example, in "living labs"; and 3) effective post-implementation monitoring and evaluation of policies.

In this regard, participatory and evidence-based policy processes are discussed as an institutional framework that guarantees the formulation of effective, efficient, and sustainable development policies (see, for example, Henning et al. 2019). Participatory policy processes correspond to multistakeholder processes that enable an interactive knowledge exchange between science, society, and politics. In this exchange, non-governmental stakeholders represent the heterogeneous interests of different social groups; that is, they mediate between an evaluation of the different SDGs from society's perspective and that of formal political decision-makers. The integration of science organizations also allows for an interactive exchange between science, society, and politics; this induces evidence-based policy processes where, on the one hand, scientific knowledge is integrated into political decision-making and, on the other, practical political knowledge of governmental and non-governmental stakeholders is integrated into the science via participatory modeling. Practical political knowledge of stakeholders particularly includes knowledge of the efficiency of the specific policy programs and implementation mechanisms encapsulated in $\theta(\mu)$. Overall, effective policy processes include:

- **Advanced policy analysis**, that is, scientific modeling approaches that explicitly take fundamental uncertainty into account. In this regard, the CGPE approach, which combines metamodeling and Bayesian averaging techniques with general equilibrium models, is a promising framework that derives optimal policy choices that take fundamental model uncertainty into account (see Henning, Badiane, and Krampe 2018; Henning, Tankari, and Ziesmer 2025; Ziesmer 2024; Ziesmer et al. 2023).
- **Policy learning** that involves an interactive knowledge exchange between science, society, and politics. These should be organized into multistakeholder policy networks comprising governmental and non-governmental

organizations that enable effective policy learning through a combination of communication and observational learning. This includes:

- **Communication learning**, which corresponds to belief-updating processes via communication between stakeholders. The latter is organized into social networks where final stationary beliefs are determined by specific network structures. Effective participatory policy processes thus correspond to *designing policy network structures* that integrate effective aggregation of individual political knowledge (Henning et al. 2019).
- **Observational learning**, which corresponds to policy-belief updating that is based on observed policy impacts. Observational learning thus depends *on effective monitoring and evaluation (M&E) systems* that allow for post-implementation assessments of policy impacts. Furthermore, large-scale policy experiments undertaken in *living labs* are especially effective mechanisms for learning the effectiveness of different policy programs and implementation mechanisms. They can reveal, for example, which factors drive technology adaptation at the individual farm level, or the ways in which effective research and knowledge systems can be designed to promote the rapid generation and dissemination of knowledge.

## Conclusion

The transformation of African agrifood systems stands as one of the continent's most critical imperatives for achieving inclusive economic growth, eradicating poverty, enhancing food security, and advancing environmental sustainability. By identifying the roles of the different technological innovation pathways, public investment strategies, and governance models, this paper presents a rigorous and multidimensional framework for understanding and guiding this transformation.

At its core, the analysis reveals that technology alone is not a panacea. Digital, biological, and conventional agricultural technologies offer distinct advantages that range from climate resilience and nutrient enhancement to improved market connectivity and input efficiency; however, their transformative power depends on the broader ecosystem in which they are embedded. Technologies can only deliver widespread impact if institutional capacity, infrastructure, market access, and policy incentives are well aligned.

Empirical evidence from Asia and Latin America shows that sustained agricultural productivity growth, driven by well-structured public investment and policy support, has been instrumental in drastically reducing poverty and undernourishment. Africa's divergence from this trajectory underscores the urgent need for more strategic, targeted, and context-specific public investments. Simply increasing agricultural budgets is insufficient; the critical difference stems, instead, from how funds are allocated, especially across research, extension, infrastructure, and organizational innovations. The analysis demonstrates that there is no "one-size-fits-all" formula for prioritizing allocations; instead, countries must tailor their strategies on the basis of structural conditions, institutional maturity, and local development goals.

The paper distinguishes between three innovation pathways: 1) technological progress (tp), 2) technical efficiency (te), and 3) transaction cost reduction (tc). It also maps the corresponding public policy levers that influence them. This approach allows for a more nuanced understanding of how growth can be generated and sustained. Biotechnology, for instance, tends to drive frontier-pushing innovations (tp), while digital tools and e-cooperatives can enhance both efficiency and connectivity (te and tc), especially among marginalized smallholders.

Even the most optimal technical interventions risk failure; however, if the political economy of policymaking is not addressed. A paradigm shift in governance is required due to fundamental model uncertainty, in which decision-makers face incomplete knowledge about policy outcomes. Rather than relying on simplistic heuristics or donor-driven agendas, African governments should institutionalize participatory, evidence-based policy processes that bridge the gap between science, politics, and society. This includes fostering multistakeholder platforms, promoting policy experimentation (for example, living labs), and investing in systems of policy learning and adaptation.

To this end, even if one overlooks the classical political incentive problems, transformational change is not merely a technical challenge; rather, it is deeply political and institutional. Effective reforms must therefore tackle both political incentive and knowledge problems. Interestingly, empirical political economy studies that assess the incentive problems and knowledge gaps in CAADP processes in African countries imply that policy failure is much more a political knowledge problem than a political incentive problem (see Henning et al. 2018).

Future reforms thus demand an enabling policy environment where transparency, accountability, and inclusivity are embedded in governance structures. Importantly, this also means embracing differentiated strategies that empower not only women, youth, and smallholders, but especially the science sector, which has historically been excluded from formal innovation systems.

This analytical framework aligns closely with the 2025 Nobel Prize-winning insights from Aghion, Mokyr, and Howitt, which collectively affirm that innovation-driven growth is both endogenous and cumulative (Mokyr 2025). They demonstrate that societies prosper when they convert knowledge into productivity through institutions that reward curiosity, protect experimentation, and manage the costs of transformation. For Africa, building such a virtuous cycle of innovation means enabling both creative destruction and creative diffusion—ensuring that new ideas displace inefficiency while broadening opportunities for all participants in the food system

Looking ahead, the path to sustainable agrifood transformation in Africa will require:

- A reimagining of investment strategies that prioritize long-term gains over short-term fixes,
- Integrated technology adoption policies that address bottlenecks across the food value chain,
- Stronger institutional frameworks for regulation, education, research, and extension, and, most critically,
- An inclusive governance model that enables collective intelligence, dynamic learning, and the political will to act on scientific evidence.

By embracing these principles, African countries can begin to close the development gap and unlock the full potential of their agrifood systems, not only as engines of economic growth but also as pillars of resilience, equity, and ecological stewardship. Ultimately, unlocking Africa's agricultural transformation demands not just smart technologies but also smart policies and institutions capable of turning potential into performance.