18 Harnessing biotechnology to release the potential of the bioeconomy for Africa

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1 Introduction

Approximately 123 million people (12% of the population) in sub-Saharan Africa (SSA) are acutely food insecure, suffering from chronic malnutrition and unable to meet their minimum food consumption needs (Diogo et al., 2022). Climate change is increasingly threatening to reverse the achievements made in the fight against hunger and malnutrition across SSA with lasting adverse macroeconomic effects on economic growth and poverty (FAO, 2015; Diogo et al., 2022). Moreover, about 70% of the very poor live in rural areas, depending almost entirely on agriculture, a sector severely affected by climate change for their livelihoods, producing approximately 80% of the food consumed in Asia and SSA (IFAD, 2011; Antwi, 2013). Climate change, therefore, negatively impacts Africa's natural ecological systems retarding the capacity for human development and food security, and poses a huge risk to millions of people who are reliant on climate-sensitive resources for their livelihoods (Descheemaeker et al., 2016). For instance, expected changes in temperature, rainfall, and wind patterns attributed to climate change are predicted to have a dramatic effect on the prevalence of one of the most dangerous migratory pests (desert locusts) in Africa and will potentially have devastating impacts on crop yields (Tang et al., 2023). The area suitable to banana bunchy top disease, an invasive and transboundary disease is expected to expand from the low and humid zones of west and central Africa to the currently cooler altitude in the eastern Africa with global warming (Bouwmeester et al., 2023). Similarly, impacts of climate change on animal health especially for vector-borne diseases have also been well documented (Lacetera, 2019). Diseases including West Nile virus, bluetongue or Lyme's disease and schistosomiasis are expected to expand into new areas with outbreaks of Rift Valley fever in East Africa being associated with increased rainfall and flooding due to El Niño-Southern Oscillation events (Caminade et al., 2019; FAO, 2015; Porter et al., 2014).

Climate change is not the only threat to food security. There are number of other issues including regional conflicts, depletion of natural resources, institutional factors, and more (von Braun et al., 2023). The issues mentioned are interlinked with each other and are characterized by a high degree of complexity complicating identifying appropriate strategies for improving food security. Nevertheless, there is general agreement that technological change is important for the strategies of improving food security and that food security is more than just increasing the quantity and availability of food produced (Directorate-General for Research and Innovation of the European Commission et al., 2022; German Science and Humanities Council, 2023; Trigo et al., 2023). Further, economic research has shown food security at household level depends on the purchasing power of households which can include many sources in addition to the production of food as already pointed out by among other Nobel Laureates Theodor W. Schultz (1980) and Amartya Sen (1983) several decades ago. One of the solutions for increasing the

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purchasing power of households via technological change is increasing the efficiency of using biological resources or the bioeconomy. Bioeconomy, here, is understood as the conversion of biological resources into food, feed, fibre, fuel, and further products (4+1Fs). The bioeconomy (Figure 18.1) has been considered to have a high potential to address a number of the challenges and contributing to sustainable development (Trigo et al., 2023). However, the contribution of the bioeconomy is complex and depends on several factors as discussed below.

2 Bioeconomy potential for Africa

Africa is rich in biological resources. Investing in the bioeconomy has a high potential for generating sustainable development in Africa. The performance of the bioeconomy is complex as illustrated in Figure 18.1. The performance of the bioeconomy is influenced by policies, national strategies, and legislation at national and international level. There are a number of driving forces for change that have an impact on the supply and use of biomass. The supply and use of biomass depends on the availability in quantitative terms including the amount of land and water available and their qualities, the quality and quantity of labour supply, and the kind of biomass production systems including the by-products and waste.[1] Policies, public and private sector strategies, and the legal environment further have an impact on the use and supply of biomass. The results that the supply and use of biomass generates can be measured against a number of societal objectives. These societal objectives are implemented via policies, strategies,

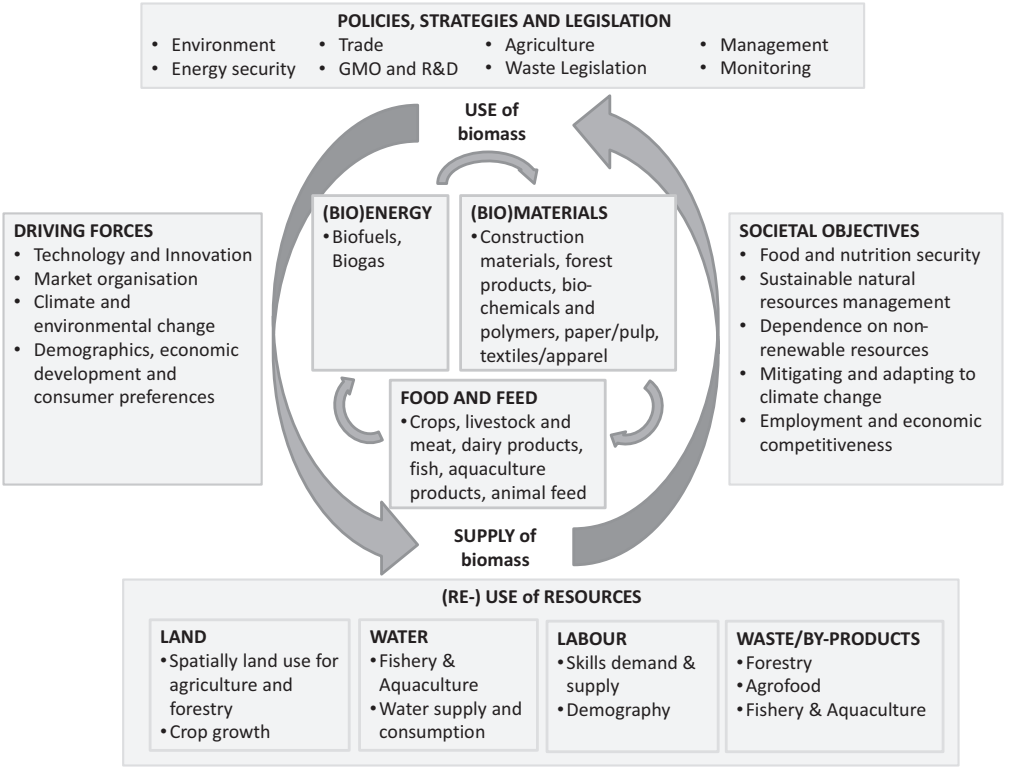

Figure 18.1 Food, feed, fibre, fuel, and further materials (4+1Fs) in the bioeconomy.

Source: Adapted from Kardung et al. (2021).

and legislation. Further, the whole system has to be seen as an evolutionary system developing over time. The system depicted in Figure 18.1 allows bioeconomy strategies to be assessed.

Several member states of the European Union and Latin American countries have developed national bioeconomy strategies with the expectation to improve the efficiency of the development of the bioeconomy towards achieving societal objectives. Only a few African countries such as South Africa and the East African Community under BioInnovate initiative have a dedicated bioeconomy strategy (M'Barek & Wesseler, 2023; EAC, 2022). Such a strategy is not essential, but having a national strategy indicates to what extent the bioeconomy is considered to be of importance (Poku et al., 2018).

Producing food remains the most important role of the African bioeconomy and fuel (energy) from biological resources is of economic importance in many parts of Africa in particular for food preparation. In these sectors there is an endogenous growth potential using comparative advantages for further economic differentiation via specialization (Zilberman et al., 2018). Productivity differences in one sector can generate substantial spill-over effects on other sectors and via differentiation in production driven by differences in relative productivity down the supply chain further stimulate economic growth. This has been shown at the theoretical level by Acemoglu and Azar (2020) and supported by empirical evidence from the bioeconomy for the European Union by Cingiz et al. (2021). M'Barek and Wesseler (2023) argue that there is no reason to expect why this should not also be the case for Africa and other parts of the world. The growth potential can be further supported by technological change. Many solutions for increasing the productivity of the bioeconomy are already available, as indicated by yield differences in crop production (Tittonell & Giller, 2013). There is a huge potential for increasing the timber supply for local infrastructure and more (Degnet, 2021). The same applies further down the supply chain when assessing food production (Cingiz et al., 2021). Technological change will not only be needed for generating economic growth on its own but also for responding to the challenges posed by climate change.

3 Contribution of bioeconomy in mitigating climate change effects

Estimates show that, globally, food systems are responsible for approximately 60% of terrestrial biodiversity loss, 24% of the greenhouse gas emissions, 33% of the soil degradation, and 61% of the depletion of commercial food stocks (UNEP, 2016). Development of a sustainable bioeconomy to accelerate mitigation and adaptation to climate is particularly relevant for Africa which is warming faster than the global average (Oguntuase & Adu, 2021). Circular bioeconomy, through enhancing and sustainable management of renewable natural resource capital, creates an opportunity to combat climate change and improve environmental health and agricultural productivity while also contributing to economic growth and job creation (Hetemäki & Kangas, 2022; IICA, 2019). For instance, practices such as cultivating on degraded land, regenerative land use, natural pest control, appropriate multi-cropping, and soil and water conservation measures increase agricultural productivity while also contributing to climate change mitigation (IPCC, 2019). Sustainable silviculture, afforestation, and reforestation are crucial in sustaining ecosystems, air quality, and soil carbon sequestration in addition to reducing vulnerability to disease and extreme weather events. By transferring carbon into soils through falling leaves and branches, forests can improve soil organic matter. Generally, forests act as natural carbon sinks and some of their products are substitutes for emissions-intensive materials and forest-based bioenergy involving the utilization of post-consumer wood and forest residues not suitable for production of other materials contributing to emission-free energy production, thereby reducing emissions (Schmid et al., 2022). Bang et al. (2009) projected that industrial biotechnology,

biofuels, and bioenergy can potentially reduce global greenhouse gas emissions by 1.0–2.5 billion tons of carbon dioxide (CO_2) per year by 2030. More recent assessments suggest that this is very much at the lower end and expected emission reductions are more than twice as large (Zahed et al., 2021).

4 The importance of biotechnology

Many experts expect that climate change will change pest and disease pressures in agriculture, forestry, and fishery requiring solutions different from those currently available. New developments, such as biotechnology can help to address these challenges and contribute to sustainable development and food security (Wesseler & von Braun, 2017). The use of new plant and animal breeding technologies such as Clustered Regularly Interspaced Palindromic Repeats-CRISPR associated protein(CRISPR-Cas) allows to breed plants and animals with higher temperature tolerance or disease resistance (FAO, 2022). These are considered relatively low-hanging fruits.

The report by FAO (2022) and other publications (Pixley et al., 2022; Falck-Zepeda et al., 2022) provide recent reviews. Some examples are of importance for Africa (Table 18.1). Several Africa-based breeders and their partners (including the Consultative Group for International Agricultural Research) are employing CRISPR-Cas9 technologies to breed for disease and pest resistance, climate resilience, and nutrition enrichment.

The African Agriculture Technology Foundation (AATF) has developed a transgenic pod borer-resistant cowpea (*Vigna unguiculata* [L] Walp.). The first cultivation started in Nigeria in 2019. Cowpea is an important staple crop, often referred to as "poor man's meat", and insect resistance has the potential to reduce yield losses while also contributing to food security (Wesseler et al., 2017). Several other applications using modern biotechnology in crop breeding for food security are available. The contribution to reducing malnutrition and micronutrient deficiency is often higher in economic terms than any direct yield effects (Wesseler et al., 2017).

The development of pest resistance using transgenic methods is also expected to protect against the invasion of the Latin American variant of the fall armyworm (Van Den Berg et al., 2021). Biological control methods such as low-risk pesticides offer the opportunity to address pest and disease problems with less negative impacts on the environment than commonly used pesticides. New developments in nitrogen fixation of plants and nitrogen supply via microbes

Table 18.1 Examples of CRISPR/Cas9-based crops for Africa

Species	*Trait targeted*
Banana	Fungus protection
	Protection against bacterial wilt
	Protection against banana streak
Cassava	Reduced cyanide levels
	Virus resistance
	Stress resistance and high yielding
Sorghum	Increased protein content
	Striga resistance
Rice	Resistance to fungal diseases
	Stress resistance and increased yields
Maize	Drought resistance
	Lethal necrosis disease resistance
Beans, maize, and cassava	Nutrition improvement

Sources: FAO (2022), Pixley et al. (2022), and Falck-Zepeda et al. (2022).

hold high promises. They may allow to produce higher yields without the high level of greenhouse gas emissions related to producing nitrogen fertilizer (ammonia) via the Haber-Bosch process which contributes more than 1% to the total emission of CO_2. If the nitrogen rates used in the European Union (EU) are applied to agricultural land in Africa, ammonium fertilizer use worldwide will increase by about 60% implying an increase in CO_2 emission from fertilizer production by about the same magnitude. These are averages but illustrate the challenge and the benefits to be expected from nitrogen supply via microbes. Still, many of the promises made at a very early stage of development may take several years if not decades before reaching farmers in the field.

New developments in the bioeconomy allow not only to improve crop production, but also to increase the efficiency in the use of biological resources more generally. The recycling of biological resources, the use of biological resources for the development of biopolymers, and precision fermentation for food production are only a few of the recent developments. Many of these technical developments are happening outside Africa and transferring those technologies to Africa can help to generate the needed sustainable economic growth. Argentina and Brazil serve as examples where modern biotechnology has generated economic growth of the bioeconomy in the global south (Deciancio & Mac Clay, 2023; Maximo et al., 2022; Follador et al., 2019).

5 Institutional challenges

The development of the bioeconomy in Africa holds promise as described above. The realization of these promises depends on the successful adoption of the technical changes needed, which is largely an institutional problem. Institutions in this context are understood as the norms and values a society holds that are translated into policies generating economic incentives and disincentives (Acemoglu & Robinson, 2012). The institutional environment has to be supportive for the investments needed at farm level and beyond and changes are needed to generate a supportive investment environment. New developments in the bioeconomy are often delayed and blocked by policies. A pest-resistant transgenic event for corn, Bt corn, was submitted for approval for cultivation in Kenya in 1998 by Monsanto (now Bayer Crop Science). In the last year progress has been made by allowing large-scale field trials as part of the approval process, yet still, after 25 years, no Bt corn variety has been approved for cultivation in Kenya. A number of issues related to the cultivation of Bt corn remain, such as the varieties being introduced are hybrid yellow corn varieties for animal feed and not for food. The effectiveness of the protection against insect pests has also been put into question. Still, this is seen as an unreasonable argument for blocking the introduction by many scientists from Africa (Paarlberg et al., 2024). Similarly, trials with a bacterial wilt-resistant banana in Uganda started in 2006 (Kikulwe, 2010). Yet until today, the bacterial wilt-resistant banana has not received approval for cultivation (Falck-Zepeda et al., 2022). Such long delays in approval have a strong negative effect on private sector incentives to invest in developing solutions for farmers (Wesseler et al., 2023). This does not only hold for solutions that are related to gene editing but also applies to the approval of biological control options in agriculture production (Fredericks & Wesseler, 2019). Examples of biological control include management of the red spider mite (*Tetranychus urticae*), a pest in vegetable production, using the naturally occurring fungus *Beauveria bassian*a strain R444 or the naturally occurring virus *Spodoptera littoralis nucleopolyhedrovirus* (SpliNPV) as control against the fall armyworm (*Spodoptera frugiperda*) or the African cotton leafworm (*Spodoptera littoralis*). There are many more solutions under development (see, e.g., Lorsbach et al., 2019). Biological control options are often more expensive as their markets are smaller making them less attractive to be developed for African markets. Regional harmonization of policies can

reduce approval costs and increase the market size stimulating private sector investment and increasing the return to public sector investment (Purnhagen & Wesseler, 2019). Yet approval of a new technology for agriculture production will not automatically imply economic success for the technology provider. If Bt corn is not successful economically, the provider of the technology will have to bear the costs of the failure, which provides strong incentives for the provider of the technology to ensure economic success.

The creation of World Trade Organization (WTO) and the subsequent formulation of TRIPS (Trade-Related Aspects of Intellectual Property Rights) created new challenges for intellectual property rights (IPR) policy and law in SSA. Many countries did not have the necessary institutions in place to implement the TRIPS agreement. They were also facing the trade-off between protecting IPR according to the TRIPS agreement and the possibilities of free-riding on intellectual property (Lele et al., 1999; Smith et al., 2021). This necessitated the understanding of the strategic importance of IPR towards social economic development to help in designing policies that address national development goals in SSA (Sikoyo et al., 2006).

Mechanisms for public and private governance will be important as African states embrace the bioeconomy. In so doing, proper Intellectual Property (IP) laws need to be formulated and enforced in Africa to boost its investment in the bioeconomy. This can be achieved by working closely with the global IP community and supported by the regional bodies (LawTeacher, 2013) such as African Union (AU), East African Community (EAC), and Economic Community of West African States (ECOWAS). Bößner et al. (2021) recently reviewed and discussed the different forms of governance that may govern the bioeconomy, ranging from international to national dimensions. The authors argue that although the global bioeconomy governance may play a fundamental role, it may experience several flaws and challenges. They recommended that the regional bodies may be the most promising ways to addressing challenges and opportunities that may arise with governance of bioeconomy pathways. For instance, the global patents and IPR are a relevant issue for bioeconomy pathways as they generate a conducive enabling environment for innovation but may be very costly and stringent for Africa. To break this barrier, proper procedures for IPR, capacity building in IPR management, and building new and strong partnerships are crucial in the governance and regulation of the bioeconomy (Falck-Zepeda et al., 2022).

6 The way forwards

The development of new biotechnology solutions by Africa for Africa and the harmonization of approval processes for new technologies can make new solutions available for the market. The development of Bt cowpea mentioned above serves as an example of how a solution can be developed over a relatively short period of time. Many more opportunities exist as mentioned above with respect to the use of new plant breeding technologies.

Several African countries are currently developing policies for IP. The EAC, for instance, has drafted a Regional Policy for Intellectual Property[2] governing the bioeconomy in East Africa. Article 43 of Protocol on Common Market calls for the EAC partner states to harmonize the IPR. This is aimed to encourage technical innovation and promote industrial and commercial use of such innovations to contribute to the social, economic, industrial, and technological development of Africa. This in turn will simulate research, access to technology, and enterprise growth. A clear and right mix of policies needs to be developed to have the desired bioeconomy future providing the incentives needed for stakeholders to engage (Gatune et al., 2021). The international community can support this process by supporting the institutional change needed (Directorate-General for Research and Innovation of the European Commission et al., 2022).

Notes

1 The term "waste" is somewhat controversial as according to the mass balance nothing is lost, but appears at different places over time and space. At some places we observe accumulation of carbon in the atmosphere or nitrogen in groundwater causing economic damage via climate change-related damages and groundwater-cleaning costs.
2 https://easteco.org/development-of-the-east-african-regional-policy-for-intellectual-property/.

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