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Building a resilient bioeconomy

Unlocking Africa's potential by harnessing sustainable growth from biomass valorisation
Paper on Bioeconomy, presented at MACS G20 – South Africa presidency, May 26, 2025

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Abstract

A well-developed bioeconomy supports food security by promoting sustainable production, reducing biomass residues and waste, diversifying diets, and building resilient food systems. What kind of bioeconomy a country desires can be achieved by a well-designed bioeconomy strategy. This depends on the (potential) availability of biomass, which in turn is dependent on natural resources, technology, and national and global societal objectives. Next to a definition of a sustainable bioeconomy, the development of bioeconomy strategies, a framework is presented that can address and assess the complex relationship between bioeconomy and societal objectives and can help to design a bioeconomy strategy that serves human well-being. Many African countries are rich in biomass resources. In the African context, food security is a primary societal objective. Developing a bioeconomy can increase food security by increasing employment and income opportunities and thus improving access to food. Health can be enhanced by nutritious diets and bio-pharmaceuticals (e.g. vaccines). The production of bioenergy demands a very large amount of biomass and, consequently, alternative renewable energy sources such as sun and wind should be considered. A focus on biomaterials could replace fossil based materials, requires relatively small amounts of biomass and captures and stores carbon from the atmosphere. A bioeconomy must be carefully designed to take full account of potential synergies and trade-offs. We conclude with suggestions for possible policy interventions that G20 member states could implement to balance fossil resource dependency with food security, while releasing the potential of the bioeconomy.

1. Introduction

Many countries have developed a specific strategy to steer towards a sustainable bioeconomy (Gardossi et al., 2023). Yet, what is meant by a sustainable bioeconomy varies between countries. Since the bioeconomy is intended to stimulate international trade, the lack of an internationally accepted definition of a sustainable bioeconomy precludes the measurement and monitoring of a sustainable bioeconomy. This paper reviews the various definitions currently in use and aims to establish a common definition of a sustainable bioeconomy, one that allows for performance measurement on an internationally comparable basis. The growing attention for a bioeconomy strategy is described in section 3. A general framework is presented in section 4, which can address and assess the complex relationship between bioeconomy and societal objectives, and can help to design and assess a bioeconomy strategy. Challenges related to the bioeconomy: implications for food security, environmental pressures and biodiversity are described in section 5. Section 6 assesses the opportunities for a sustainable bioeconomy in the African context. In particular, we address the questions to what extent the bioeconomy can reduce the dependency of energy and material production on fossil-based finite resources and what the potential impact of the bioeconomy on food security may be. We conclude with suggestions for possible policy interventions that G20 member states could implement to balance fossil resource dependency with food security, while releasing the potential of the bioeconomy. One foundational recommendation is greater institutional cooperation.

2. Key definitions and concepts of the bioeconomy

In this section we review the key concepts and definitions of the bioeconomy. It is that part of the economy that relies on biological sources. Simply put, a bioeconomy is about the conversion of biological resources into food, feed, fibre, fuel, and further products (Kikulwe and Wesseler, 2025), the latter of which can include chemicals, pharmaceuticals or other biomaterials. The bioeconomy, or biobased economy, therefore also focuses on replacing fossil resources, such as coal, oil and natural gas in fuels and further products. A transition to a biobased economy is therefore expected to reduce the dependency on (the import of) fossil fuels, while contributing to the mitigation of climate change and environmental protection.

The bioeconomy has an inter-sectoral, (inter)national, and transdisciplinary nature, which is reflected in a variety of definitions and delimitations (Kardung et al., 2021). The way in which the term is defined and in which its activities are delimited depends on the perspectives of stakeholders: scientists, policymakers, NGOs, or the private sector. Bugge et al. (2016) identified three distinct visions of the bioeconomy - biotechnology, bio-resource, and bio-ecology - each associated with different actors and reflecting their priorities. Furthermore, the bioeconomy is considered to be pervasive nature, not only for a specific sector but increasingly integrated into day-to-day life, in a similar way to digitalisation (Wesseler and von Braun, 2017). A clear scope is necessary for discussing, monitoring, measuring and assessing the bioeconomy and its contribution and impact on the grand challenges faced by global food systems. This is particularly urgent given the need to provide a growing world population with sufficient safe and healthy food, while accounting for climate change and the planetary boundaries that define a safe operating space for humanity.

The Global Bioeconomy Summit (GBS) brings together ministers and government representatives from Asia, Africa, Europe, South and North America, international policy experts from the United Nations, the Organisation for Economic Co-operation and Development (OECD), as well as high-level representatives from science and industry. In 2020, the GBS defined the bioeconomy as:

> *"the production, utilisation, conservation, and regeneration of biological resources – including related knowledge, science, technology, and innovation – to provide sustainable solutions (information, products, processes and services) within and across all economic sectors and enable a transformation to a sustainable economy" (IACGB, 2020).*

This definition explicitly recognises the role of knowledge and process-oriented steps related to biomass production and use in a sustainable economy.

The European Commission (EC) defines the bioeconomy in a similar way, but provides more details on biological resources and sectors where it is used, emphasising sustainability and circularity:

> *"The bioeconomy covers all sectors and systems that rely on biological resources (animals, plants, micro-organisms and derived biomass, including organic waste), their functions and principles. It includes and interlinks: land and marine ecosystems and the services they provide; all primary production sectors that use and produce biological resources (agriculture, forestry, fisheries and aquaculture); and all economic and industrial sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services.* ***To be successful, the European bioeconomy needs to have sustainability and circularity at its heart.*** *This will drive the renewal of our industries, the modernisation of our primary production systems, the protection of the environment and will enhance biodiversity" (EC, 2018).*

The European Bioeconomy Alliance (EBA), a cross-sectoral coalition of various bioeconomy industry associations, offers a comprehensive definition of the bioeconomy and emphasises its role in driving the transition to a circular economy.

> *"The bioeconomy comprises the production of renewable biological resources and their conversion into food, feed, bio-based products, and bioenergy via innovative, efficient technologies. In this regard, it is the biological motor of a future circular economy, which is based on optimal use of resources and the production of primary raw materials from renewably sourced feedstock" (EBA, 2016).*

Canada adopts the EC definition of the bioeconomy but relies on the world's most abundant and sustainable biomass resources. In its Bioeconomy Strategy, Canada emphasises establishing biomass supply and stewardship of natural capital, including agriculture and forestry. Biotechnology is seen as a competitive advantage, whereas Europe is recognised as having the most stringent genetically modified organisms (GMO) regulations in the world. The Canadian bioeconomy has sustainability at its core and is directed towards circularity and adding maximum value to resources, including residuals and waste (CBS, 2019).

The Department of Science and Technology in South Africa in a slightly older, bioeconomy strategy (DST, 2013) emphasises the importance of the innovation system to exploit the potential of the bioeconomy. This focus is mainly on biotechnology.

> *"Bio-economy" refers to activities that make use of bio-innovations, based on biological sources, materials and processes to generate sustainable economic, social and environmental development. In the bio-economy the entire innovation system/network, ranging from ideas, research, development, productisation and manufacturing to commercialisation, should be used to its full potential in a coordinated manner (DST, 2013)".*

Under the Brazilian G20 presidency the implementation of a sustainable and future-oriented bioeconomy is fostered. The key features of the Brazilian bioeconomy are: a) the promotion of sustainable practices; b) innovation and technological development; c) economic diversification; d) job creation and social inclusion; and e) climate change mitigation[1].

Recently, the Ministers of Agriculture from around the world, highlighted that agriculture, including crops, livestock, forestry, aquaculture and fisheries, plays a vital role in this change, since the sustainable primary production of biological resources and the resulting products and services are the foundation of a sustainable bioeconomy (GFFA, 2025).

In conclusion, it is clear that all countries or industries emphasise their specific situation, priorities and concerns in their definitions of the bioeconomy. Some highlight the technological and innovation dimension of the bioeconomy, others such as the EU, emphasise the sustainability dimension, and still others, such as Canada, the management of an abundant natural resource base. Other countries, notably those in Africa, emphasise that food security is key, and that challenges will become even more pressing due to population growth and climate change.

So, if a broad definition that suits many countries and industries is required, it will naturally become more general. A widely and internationally accepted definition given above (IACGB, 2020) appears to be the most useful, but we potentially recommend adding the circularity principle. The definition, then, becomes:

> *"the production, utilisation, conservation, and regeneration of biological resources – including related knowledge, science, technology, and innovation – to provide sustainable solutions (information, products, processes and services) within and across all economic sectors and enable a transformation towards an economy* ***that must have sustainability and circularity at its heart.****"*

3. Growing attention to the bioeconomy and its strategies

The bioeconomy, in its simplest definition, refers to an economy based on biological resources (living organisms). It is promoted by many international and national organisations due to its fundamental role in achieving societal objectives such as food and nutrition security, sustainable resource management, dependency on non-renewable resources, mitigating and adapting to climate change and creating employment. The bioeconomy can contribute to many Sustainable Development Goals (SDGs), including those related to poverty, food security and nutrition, sustainable production and consumption, climate change, biodiversity, and the environment (Trigo et al., 2023). Sixty countries now have a bioeconomy strategy and international organisations, such as G20, G7, ASEAN, FAO, UN, and WEF, highlight its role in sustainable development (IACGB, 2024).

Key drivers of the bioeconomy are increased sustainability awareness among consumers, producers and policy makers, increased recognition of human induced climate change (IPCC, 2023) and the need for a sustainable bioeconomy to achieve the Paris targets, climate neutrality and the SDGs. The COVID 19 pandemic highlighted the value of biotechnology as the vaccines were produced at unprecedented speed using the science and tools of the medical biotechnology field, saving millions of lives. The pandemic furthermore highlighted the vulnerability of being dependent on imports. On the supply side, new biotechnological insights have emerged from scientific breakthroughs. These could transform industries and society by increasing agricultural productivity and enabling the production of biofuels, fossil free materials, biochemicals, and new foods (e.g. lab-grown meat). They can also contribute to new healthcare applications and the development of new biopharmaceuticals. Biotechnology includes traditional low-tech methods, such as microbial fermentation, and advanced technologies, including bioinspired engineering (bionics), artificial intelligence and carbon capture techniques (e.g. micro algae). This has the potential to reduce GHG emissions, create new jobs, and offer local, sustainable development.

Many more developed economies (in the "Global North") have identified bioeconomy as being key for sustainability and environmental health, whereas most of the emerging economies ("Global South") value bioeconomy as key for providing food security, economic growth and jobs, food, health, and environmental security (IACGB, 2024). Developing the bioeconomy should help the emerging regions avoid the pitfalls of embedding a fossil economy.

[1] https://braziliannr.com/2024/06/09 /brazil-launches-national-bioeconomy-strategy/

Globally, about 80% of biomass supply comes from crops and livestock and the remainder from forestry, of which 75% is used as feed and food, 10% for energy and a little more than 15% for products (WBCSD, 2020). It is difficult to estimate the size of the bioeconomy but in Europe it is almost 5% of GDP and 9% of total employment (Ronzon et al., 2020).

An important starting point is the notion that land and water are limited resources. In addition, Africa as a continent is hit harder by climate change than Europe and food security remains an important issue in Africa.

4. A framework to address the complex relationship between bioeconomy and societal objectives

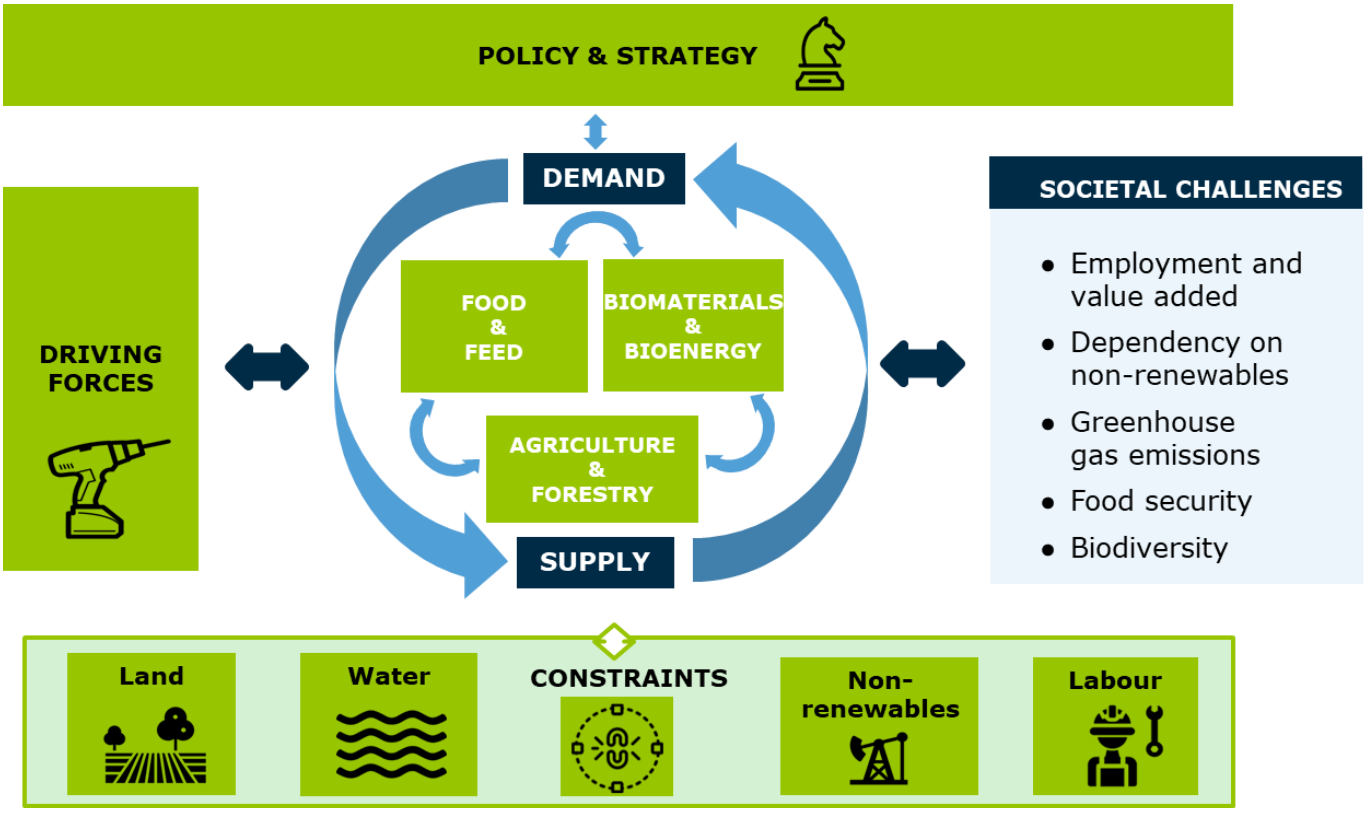

Figure 4.1 *A framework to assess and address the contribution of the bioeconomy to societal challenges*
Source: Adapted from Kardung et al. (2021).

Many African countries are rich in biomass resources, which could enable them to reduce their dependency on non-renewable resources such as fossil oil and gas. Producing food remains the most important role of the African bioeconomy and fuel (energy) from biomass resources is of particular importance for food preparation in many parts of Africa. Figure 4.1 illustrates the complex relationships between factors affecting biomass demand and supply within the bioeconomy (Kardung et al., 2021; Kikulwe and Wesseler, 2025). First, a number of (external) driving forces for change impact the supply and use of biomass, such as technological change, climate change, and changes in consumer preferences.

Second, the supply and use of biomass depends on the availability of resources such as the amount of land and water available and their qualities, the quality and quantity of labour supply, and the biomass production systems - forestry, agrifood and fisheries/aquaculture - including the availability of byproducts, residues and waste. The supply and use of biomass generates outcomes that can be measured against a number of societal objectives. If the bioeconomy is not as desired, the outcomes can be influenced by policies, national strategies, and legislation at national and international level. These policies influence the supply and use of biomass and the system is also evolutionary and develops over time. Furthermore, the whole system has to be seen as an evolutionary system developing over time.

To monitor and measure the development of the bioeconomy, a set of indicators is essential. An indicator is a quantitative or qualitative measure, which must be measurable, comparable, replicable, and responsive to fluctuations in the development. They can help policymakers and other stakeholders to understand and interpret results, reveal trade-offs between policy measures, and formulate clear targets for their policies. Bioeconomy strategies can be described using the system depicted in Figure 4.1. An assessment of the (sustainability) impacts of a strategy, however, requires a set of indicators. Kardung et al. (2021) provide (main) indicators for each of the societal challenges for the bioeconomy, including their rational, sustainability dimension and source (See Annex 1, Table A.1).

Other indicator sets focus on the three dimensions of sustainability and cover the economic, social and environmental dimensions of sustainability (Bracco et al, 2019; Mandley et al., 2020; EC-JRC, 2025). Here we also refer to an FAO-supported approach to build a monitoring and evaluation (M&E) framework that addresses these three dimensions in a balanced way but focuses on the agri-food sectors (see Annex 1, Table A.2). This framework uses a relatively limited, yet scientifically robust, set of indicators to identify impact categories, based on the principles and criteria for a sustainable bioeconomy agreed upon by ISBWG (Bracco et al., 2019)[2]. For illustrative purposes, few combinations of principles, criteria and indicators are presented in Table A.2. The methodology to arrive at an M&E framework is participatory, so that stakeholders' priorities, expert knowledge, context-specific situations, and data availability and reliability can be taken into account. It is important to point out the need to adopt a holistic approach for monitoring the sustainability of the bioeconomy. By addressing environmental, social *and* economic sustainability indicators, insight is gained into possible trade-offs or synergies of policy interventions between and within these dimensions.

5. Challenges related to the bioeconomy: implications for food security, environmental pressures and biodiversity

The FAO definition of food security (FAO, 2002; FAO, 2010) has four pillars: availability, access (affordability), use (nutrition) and stability[3]. Food security therefore has multiple dimensions, where the interests of the producer and consumer of food can sometimes be conflicting. For example, high food prices are good for farmers if increased profits are remitted back to them and can combat poverty in rural areas where agriculture is an important source of income. In contrast, high food prices are detrimental to consumers and exacerbate poverty in urban areas (Swinnen, 2011). In fact, in Africa, a large proportion of rural households are net consumers of food (Giller et al., 2021), so, there is no clear relationship between the level of food prices and food security. Another complexity is that nutritious and healthy food (i.e. with sufficient micronutrients in the form of minerals and vitamins) is often relatively expensive (e.g. FAO et al., 2020; De Steenhuijsen Piters et al., 2021).

If biomass is increasingly used for biobased products (such as biofuels, bioplastics and other materials from agricultural sources) this can increase the pressure on the food system. Competition for resources such as land and water will increase, as biobased products could come from the same crops that are used for food (e.g. maize, sugar cane, soy). Food prices may increase when more crops are converted to biofuels or bioplastics. However, crops contain several components: bioethanol production from maize also produces animal feed (DDGS). The increased demand for land can also lead to expansion of agricultural lands into natural areas and put pressure on biodiversity. Producing biomass from forests can alleviate pressure on agricultural land for food production, but has the downside of potentially damaging valuable nature and reducing biodiversity. Investments in second-generation biobased technologies (using non-food biomass) can reduce pressure on food prices and land use. Government incentives for biofuels (e.g., blending mandates and subsidies) may drive demand up artificially, impacting prices of crops that can be used as food or other non-food products. Trade policies, such as export restrictions or import tariffs on crops used in biobased production can also affect global food prices.

The question of whether increased use of crops in non-food applications can be detrimental to food security,

[2] International Sustainable Bioeconomy Working Group, established in the context of FAO's project on sustainable bioeconomy guidelines.

[3] Recently the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security (HLPE-FSN) recommended adding agency and sustainability to the four widely accepted dimensions of food and nutrition security (see Clapp et al., 2022).

however, must be placed in the broader context of the causes of food (in)security. Food (in)security is primarily driven by insufficient purchasing power (poverty) as is argued by prominent Nobel Prize laureates (Schultz, 1980; Sen, 1983). Food security is much affected by macroeconomic factors (Diaz-Bonilla, 2015; Brooks and Matthews, 2015; OECD, 2019). Indeed, macroeconomic factors influence the four components of food security through different channels. Domestic production and imports determine availability, and economic growth, generating employment opportunities and higher income levels, is strongly linked to food access. In fact, the ultimate driving force behind global food security is the overall level of economic development, affecting each of its dimensions (Timmer, 2002; Regmi and Meade, 2013).

In emerging economies where agriculture remains a dominant economic sector, further investment in the development of a biobased economy can have a positive effect on food security by boosting the sector's potential to generate employment and income. This proposition draws a parallel to the relationship between cash crops (defined as crops primarily grown for the market to generate regular income) and food security. The literature suggests a positive relationship between cash crop production and the food security of affected farmers (for a review, see van Berkum et al., 2025), but this depends on certain conditions or circumstances. For example, in Ghana expanding production of tree crops such as cocoa and cashew nuts provides farmers with better income and access to food. However, as evidence from other cases confirms, positive impacts of non-food crop production and food security depend on many factors, such as the characteristics of farm households, their communities and how cash crop production and marketing are supported, for instance through technical training, improving market access and providing modern seeds, credit and other inputs. Farmers with assets, such as their own land and/or livestock, alternative incomes that enable them to invest in the farm and/or cover differences in farm income, and access to inputs are more likely to invest in cash crops and are better positioned to take advantage of market opportunities.

Production of non-edible/cash/export crops may have negative impacts on the environment. For example, the expansion of soybean, oil palm and rubber is often linked to deforestation and biodiversity loss (Dreoni et al., 2022; Ayompe et al., 2021). However, studies on the environmental impact of palm oil cultivation in Indonesia show that farmers can use their chemical inputs much more efficiently. The same or even more can be produced with fewer inputs (Dalheimer et al., 2024; Gutierrez Al-Khundhairy et al., 2023). These and other empirical studies (e.g. Heidenreich et al., 2022) show positive impacts of the introduction of 'best practices' such as: minimising herbicide, fertiliser and pesticide input use, and applying crop residues for maintaining soil organic matter. These studies indicate that yields do not have to be lower than with 'conventional' production methods with more intensive input use, yet highlight the importance of designing effective training modalities and policies that enable knowledge to be put into practice, which includes creating marketing opportunities.

6. Opportunities to release the potential of the bioeconomy in Africa

6.1 Bioeconomy in Africa: a key role for the agricultural and forestry sectors

Achieving food security remains the most important role of the African bioeconomy and therefore the agricultural sectors need to play a central role. Africa faces serious challenges regarding future food security. De Haas and Giller (2025), in a multidisciplinary overview of African food security highlight three reasons: first, the ongoing increase in population, which will double in the next 20 years, second, the lack of sufficient jobs to make a living outside agriculture, and third, that agricultural production has mainly increased through areal expansion and to a much lesser extent by productivity increases. The challenge of solving food security is not only a technical matter, but a multifaceted, wicked, problem. De Haas and Giller (2025) identify four interrelated focus areas, all of which are crucial when food systems are considered: agriculture, ecosystems, trade and nutrition. We extended these focus areas to include more elements of non-food biomass production (forestry) and non-food biomass demand.

- **Productive agriculture:**

In general, agricultural productivity is low in Africa (Schut and van Ittersum, 2025), due to a long history of nutrient depletion and a limited use of chemical fertilisers (FAOstat, 2025). Manure is often the only source of nutrients, but is poorly managed or used as a fuel for cooking (Ndambi et al., 2019). This implies a large potential for productivity increase, by improved manure management, techniques and higher nutrient inputs. African farmers are mainly smallholders, which is likely to remain the case in the coming decades, due to a lack of jobs (i.e. non-agricultural labour opportunities). Smallholders face multiple problems, including (i) labour shortages at critical moments in the cropping season despite the high unemployment; (ii) weak institutional infrastructure, leading to high transaction costs, lack of inputs, poor regulations, and corruption; and (iii) inadequate technical infrastructure (such as roads and cooling), resulting in high post-harvest losses. This all induces a low income, high prices, and few incentives to increase productivity. Climate change and degrading soils are already aggravating these challenges. Agricultural intensification to boost yields is urgently needed (supply side, as the yield gap remains high). However, favourable market conditions (demand side) and supportive policies must also be in place to enable this. The latter also concerns policies that provide economic prospects to smallholders by facilitating access to agricultural value chains and ensuring that they receive a 'fair share' of the revenues generated (e.g. de Brauw et al., 2021 for options what can be done). For the past decades, food production has increased due to land use expansion, as the population has grown rapidly. In future, increased land pressures may lead to intensification. Locally produced 'green' nitrogen fertilisers, produced using renewable energy, represents a potentially revolutionary technology for Africa (Schut and van Ittersum, 2025). The bioeconomy requires large quantities of biomass. The currently poor productivity means that there is little surplus of crop residues beyond those needed for livestock feed or to replenish soil organic matter.

- **Productive forestry:**

Forests and woodlands cover vast areas of Africa, representing a substantial percentage of global forest cover. Tree plantations comprise a limited part of Africa's total forest area, mainly at high elevations unsuitable for agriculture. Large scale commercial forest operations are found in the plantation-based forest industry in the South, and in the concession-based timber extraction and saw milling industry in Central and Western Africa. Small quantities of plantation and naturally grown timber form the foundation of small scale forest industry across the continent. Firewood and charcoal are by far the most significant uses, but cottage industries also produce furniture, local construction material, woodcraft, utility goods, and a variety of non-wood products including fruits, medicines, fodder and honey, from various forest types. There is a growing volume of timber traded directly from farms and community managed forests to the primary forest industry, creating links between the informal and formal sectors. There are many efforts for reforestation, with the production of products such as paper and timber also taken into account.

- **Ecosystems:**

Increasing land pressure is likely to lead to land expansion, largely at the expense of forest and other nature. Forests are key for maintaining Africa's rich biodiversity, and also play a key role in the continental water cycle. Thus, agricultural expansion into currently forested land represents a major threat – not only to ecosystems but also to agriculture. Reforestation is promoted by various parties, but illegal logging still is a big problem. Agroforestry could play a role in reducing soil degradation and small scale irrigation has a large potential.

- **Trade:**

African consumers are increasingly reliant on lengthening supply chains and rising levels of food import dependency (van Berkum and de Steenhuijsen Piters, 2025). This includes imports from outside the continent, particularly wheat, rice, oil and animal products. Recently, dependency on food imports is increasingly viewed as undesirable as this eats into the trade balance, outcompetes fledgling domestic value chains, and exposes consumers to volatile prices. International food trade will continue to be an inevitable, and sometimes desirable, component of (urban) food security in many African countries. Enhancing domestic value chains can be an effective way to increase rural purchasing power, foster food self-sufficiency, and create more employment opportunities. Another option is to invest in African crops - through research, extension services, and marketing - which could lower their relative prices and increase their appeal to consumers. Finally, food security would benefit from more regional trade by removing barriers to regional trade. Promising steps in this direction have been taken by the African Union through the establishment of the African Continental Free Trade Area (ACFTA), although this is still in its infancy[4].

- **Access to nutritious food:**

Enhancing food security goes beyond increasing the supply of calories: diverse diets are essential to address the problems of malnutrition, overnutrition, and undernutrition. Africa is also increasingly reliant on a small number of staple grains and oil crops, as flours, fats and sugar are cheap on global markets. Given short-term food security challenges, healthy nutrition is often not prioritised. The change in the food system should focus on nutritious diets and not only on staples such as flours, fats, and sugars. Vegetables, fruit and animal-sourced protein should be prioritised in research, extension and marketing. A shift in focus towards nutrition-sensitive agriculture is needed.

- **Access to non-food products made of biomass:**

There are many non-food biomass uses that could boost employment and income in rural areas, improve water quality and soil health, reduce dependency on fossil fuels and enhance human health. First, there are the traditional non-food uses, including biomass for energy (e.g., wood), construction (e.g., poles, thatch, insulation materials, panels and boards), textiles (e.g., cotton) and

[4] https://au.int/en/african-continental-free-trade-area

cosmetics and personal care products (oils, waxes, extracts). In addition, there are bioplastics, (platform) chemicals and biobased materials where biomass can replace fossil inputs. Attention is also needed for biochar, which can be used for soil enhancement, water purification, and as a component in construction materials and pharmaceuticals in the forms of active compounds, plant extracts for medicines, supplements, or herbal remedies. Regarding the latter, South Africa and many other countries stressed the importance of the use of pharmaceuticals, as biotech played a key role in the development of COVID-19 vaccines. There are many diseases where bio-pharmaceuticals might help in their treatment (small biomass volume, high value added).

6.2 An analysis of the extent to which bioeconomy can reduce dependence on fossil feedstock in Africa

In general, the energy demand of human society is so large that biomass alone cannot meet this demand. This applies not only to electricity (power) generation but also to transport fuels (Bos and Broeze, 2020; Berkhout et al., 2024). The development of alternative sources is of utmost importance, especially solar cells (PV, photovoltaic), which convert sunlight directly into electricity, and represent a serious option for the African continent. In some places, also hydro-energy is an option. The South African Integrated Resource Plan (IRP) is an electricity infrastructure development plan based on the least-cost electricity supply and demand balance, considering security of supply and the environment (minimising negative emissions and water usage). It focuses primarily on the development of PV and wind (IEA Bioenergy Country report South Africa 2021), and very little on the development of bioenergy.

Electricity use in Africa

Electricity use in Africa per person is much less than the global average. The dependency on fossil fuels for electricity generation is low, but South Africa is an exception: 83% of its electricity is generated from (fossil) coal, while wind and solar contribute 12%, and bioenergy accounts for only 0,2% of its total power generation. Overall in Africa, the use of renewable sources for power generation is still limited. Despite being the sunniest continent, Africa accounted for only 3% of global power generation in 2023. The use of fossil gas is becoming increasingly common, and this burdens economies, whereas Africa has abundant renewable energy resources. The biggest challenge will be to build enough clean electricity to meet growing electricity demand and to avoid using expensive gas as a ‘bridge’ for the electricity transition. This has been successfully achieved in Kenya, with wind, solar, and geothermal power entirely meeting its demand growth since 2018 (Ember, 2025).

In addition to the production of energy and transport fuels, fossil feedstock is used to produce chemicals and materials (mostly plastics). This category of applications represents a completely different, much smaller demand size. Biomass can be used to replace fossil feedstock in these applications. Moreover, a range of materials have traditionally always been produced from biomass. There are thus two different groups of relevant crops-materials combinations: non-food crops that provide fibre and wood such as textiles, paper and board, timber, building materials, etc., and crops that provide feedstock for chemicals and materials such as bioplastics and other replacements of fossil-based materials and chemicals, etc. (Berkhout et al., 2024). This second category is presently mostly made from fossil oil. The volume of biomass needed to phase out oil in these applications is much smaller than for power generation or for transport fuels (Bos et al., 2024). Moreover, in these applications the carbon atom is used as a building block, becoming embedded in the product. As a result, it acts as a carbon sink throughout the product’s lifetime, temporarily removing it from the GHG pool. Using biomass for these categories of applications lowers the dependency on fossil feedstock for chemicals and materials, and is an integral part of the bioeconomy.

Transport fuels in South Africa

South Africa has almost no proven oil reserves. However, it has plenty of inexpensive coal. To achieve security of energy supply, South Africa produces synthetic transport fuels from coal gasification using Fischer-Tropsch synthesis, in a process with very high GHG emissions. South Africa is the only country in the world broadly applying this technology. Moving away from these synthetic transport fuels would lead to a very significant decrease in GHG emissions (IEA Bioenergy, 2024).

The South African Biofuels Regulatory Framework provides a regulatory framework for the implementation of the Biofuels Industrial Strategy of 2007 (BIS). The targeted biofuels penetration is 4.5% v/v of the national fuel pool with 2% expected to come from first generation biofuels technologies (IEA Bioenergy, 2023).

Berkhout et al. (2024) find that in Europe, the future non-food material demand, including textiles, excluding wood and wood products, under the assumption that the use of fossil oil for these products is banned, could amount to about a third of the demand for biomass for animal feed. With the high level of animal-based protein consumption in Europe, the biomass demand for feed in the EU amounts about three quarters of the current total biomass demand. The demand for non-food applications can be lowered by using more circular practices, because the carbon is not “burnt” and converted into CO_2, which allows re-use. So the new demand for non-food is a new competitor for biomass, though it is relatively small in terms of volume.

In line with earlier studies from van Zanten et al. (2018) and de Boer and van Ittersum (2018), Berkhout et al. (2024) proposed developing a system where livestock production relies solely on grass and by-products, instead of the current practice of dedicating agricultural production to crops for feed. In the Berkhout et al. (2024) approach, non-food (materials and chemicals) are considered as fulfilling direct human consumption needs, based on the assumption that they are essential for human demand or basic human needs, even if not consumed as food. These can be produced both from unused side streams of food production processes and from direct cultivation. By-products of cultivation for non-food production can still go to livestock farming. Since carbohydrates are a particularly suitable feedstock for materials and chemicals, the by-products (mainly proteins) are well-suited for livestock feed. So, there can also be synergy effects. For example, a split between protein and carbohydrate as a result of the production of plant-based protein leads to a higher availability of carbohydrates, which can be used for chemicals and plastics. The bioeconomy is about balancing crops and needs.

7. A bioeconomy strategy is needed for the sustainable use of natural resources to support human well-being

Moving from the Africa focus, back to a more general focus, we can conclude that the bioeconomy can deliver on the societal objectives (enhancing food security, biodiversity and employment opportunities, reducing dependency on non-renewables, and adapting and mitigating climate change). A rise in biobased non-food demand might reduce dependency on non-renewables, mitigate climate change, and creates employment. However, it may also cause challenges regarding food security and biodiversity. The challenge remains the sustainable use of natural resources to support human well-being. A bioeconomy strategy therefore needs to emphasise:

- Sustainable agricultural practices: the bioeconomy promotes sustainable farming using biological resources and innovations (e.g. biofertilisers, biopesticides and precision agriculture) to enhance crop yields and increase resilience to climate change and generate a living income, thus contributing to food security.
- Resource efficiency: the bioeconomy emphasises the efficient use and reuse (e.g. turning food waste into animal feed or bioenergy) of biomass, which reduces losses in the food system, enhancing food availability and affordability, thereby improving access to food.
- Diversification of diets: development of alternative proteins (e.g. plant-based, insect-based, or lab-grown meat) in the bioeconomy reduces pressure on traditional food systems and contributes to meeting growing food demand and reducing dependency on vulnerable supply chains.
- Climate Resilience: bioeconomic innovations like drought-resistant crops or carbon-smart farming help mitigate and adapt to climate change, which directly affects food production and stability.
- Rural Development: the bioeconomy can stimulate rural economies by creating jobs in bio-based industries, enhancing local food systems and income, thus improving access to food.
- Enhancing health and reducing diseases: there are many diseases, especially in Africa, for which bio-pharmaceuticals (e.g. vaccines) might help to reduce child mortality, improvement of maternal health and reducing the burden of HIV, malaria and other diseases.
- Policy and Innovation: integrating bioeconomy strategies with national food, economic and science & innovation policies need to lead to more resilient and inclusive food systems.

In summary, a well-developed bioeconomy supports food security by promoting sustainable production, reducing waste, diversifying diets, and building resilient food systems. What kind of bioeconomy a country desires can be achieved through a well-designed strategy The latter depends on the (potential) availability of biomass, which in turn depends on natural resources, technology, national and global societal objectives. In the African context, food security is a primary societal objective. Developing a bioeconomy can increase food security by increasing employment and income opportunities and thus improving access to food. Food security is key but is dependent on many factors other than the availability of biomass. Health can be enhanced by nutritious diets and bio-pharmaceuticals (e.g. vaccines). A focus on bioenergy demands a very large amount of biomass and, consequently, alternative renewable energy such as solar cells and wind should be considered. A focus on biomaterials could replace fossil-based materials, requiring relatively small amounts of biomass and capturing and storing carbon from the atmosphere. Non-food demand for agricultural produce and processing can also create employment and income in rural areas. A bioeconomy must be carefully designed to take full account of potential synergies and trade-offs. A framework is presented that can address and assess the complex relationship between bioeconomy and societal objectives and that can help design a bioeconomy strategy that serves human well-being.

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Annex 1 Tables

Table A.1 *Proposed list of indicators by societal objective for the framework (See Figure 4.1)*

Main Indicator	Rationale	Sustainability Dimension	Source
1. Food and nutrition security			
Availability of food	To assess the contribution of the bioeconomy to food and nutrition security, based on the widely accepted four dimensions of food security	Society	FAO [101]
Access to food			
Utilisation			
Stability			
2. Sustainable natural resource management			
Sustainability threshold levels for Bioeconomy Technologies	New indicator based on genuine investment theory with a focus on the bio-based economy	Environment	Own elaboration, Bartolini et al. [102], Wesseler et al. [103]
Biodiversity	Indispensable to assess the impact of biomass production at the genetic, species, and ecosystem level	Environment	SAT-BBE [12], Bartolini et al. [102], Plieninger et al. [104], Strohbach et al. [105], Weikard et al. [106]
Land cover	To assess land use conflicts	Environment	Lier et al. [88]
Primary Biomass production	To assess biomass availability	Economy	BERST [95]
Sustainable resource use	To assess the sustainability of biomass production	Environment	Lier et al. [88]
3. Dependency on non-renewable resources			
Bio-energy replacing non-renewable energy	To assess the direct substitutability of fossil resources with biological resources	Environment	Own elaboration
Bio-material replacing non-renewable resources	To assess the direct substitutability of fossil resources with biological resources	Environment	Lier et al. [88]
Biomass self-sufficiency rate	To assess independency from biomass imports.	Economy	Own elaboration
Material use efficiency	To assess the degree of circularity	Economy	Lier et al. [88]
Certified bio-based products	To assess the variety of products from bio-based production	Environment	Own elaboration
4. Mitigating and adapting to climate change			
Greenhouse gas emissions	Traditional indicator applied to bioeconomy sectors	Environment	EUROSTAT [96]
Climate footprint	To assess CO_2 emissions for sectors based on life cycle assessments of bio-based production	Environment	Own elaboration
Climate change adaptation	More indicators of adaption to climate change impacts are needed	Environment	Own elaboration
5. Employment and economic competitiveness			
Innovation	Traditional indicator applied in more sectorial and spatial detail	Economy	Lier et al. [88]; SAT-BBE [12]; Own elaboration
Investments	To assess biomass flows within the EU between the rest of the world	Economy	Lier et al. [88] Bartolini et al. [102]
Value Added of the bioeconomy sectors	To assess product uptake of bio-based production	Economy	Lier et al. [88]
Comparative advantage	To assess biomass flows within the EU between the rest of the world	Economy	Own elaboration
Production and consumption of non-food and feed bio-based products	Traditional indicator applied in more sectorial and spatial detail	Economy	Own elaboration
Import and export of bioeconomy raw materials and products	To assess biomass flows within the EU between the rest of the world	Economy	Own elaboration
Employment	Traditional indicator applied in more sectorial and spatial detail	Society	Lier et al. [88]
Bioeconomy-driving policies	To assess policies, strategies, and legislation on the bioeconomy	Society	Own elaboration

Source: Kardung et al., 2021.

Table A.2 *Sustainable bioeconomy principles & criteria, and related impact categories*
Colour code: Economic Social Environmental.

Principles	Criteria		Indicator categories
Principle 1. Sustainable bioeconomy development should support food security and nutrition at all levels	Criterion 1.1. Food security and nutrition are supported	1.1a	Food security
		1.1b	Nutrition
	Criterion 1.2. Sustainable intensification of biomass production is promoted	1.2a	Domestic biomass production
		1.2b	Yield/agricultural productivity
		1.2c	Land for biomass production
	Criterion 1.3. Adequate land rights and rights to other natural resources are guaranteed	1.3a	Land rights
		1.3b	Rights to other natural resources
	Criterion 1.4. Food safety, disease prevention and human health are ensured	1.4a	Food safety
		1.4b	Disease/hazards prevention (in biomass production and processing)
		1.4c	Human health
Principle 2. Sustainable bioeconomy should ensure that natural resources are conserved, protected and enhanced	Criterion 2.1. Biodiversity conservation is ensured	2.1a	Biodiversity conservation
	Criterion 2.2. Climate change mitigation and adaptation are pursued	2.2a	Climate change mitigation (carbon and other GHG emissions)
		2.2b	Climate change adaptation
	Criterion 2.3. Water quality and quantity are maintained and, in as much as possible, enhanced	2.3a	Water quality
		2.3b	Water quantity/use/efficiency
	Criterion 2.4. The degradation of land, soil, forests and marine environments is prevented, stopped or reversed	2.4a	Land use change
Etc.	Etc.	Etc.	Etc.

Source: Bracco et al., 2019, Table 1, p. 8-9. Note: ISBWG has identified 10 principles, 24 criteria and 69 impact categories.

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