health issue where women and children in particular face high risks from exposure of household air pollution.

A bioeconomy, where fossil-based resources are replaced with renewable biobased resources provides a great potential for climate change mitigation and adaptation both in terms of carbon neutrality (e.g., carbon sequestration) and improved resilience. Transforming the agro and bio processing sector so that it effectively adds value to the primary production in an environmentally friendly manner will therefore be a key issue in an African bioeconomy agenda. The bioeconomy is also critical for protecting and restoring biological diversity and ecosystems in the areas of agriculture, marine systems, freshwater systems, but also for providing solutions in urban planning and infrastructure. Examples include replacing unsustainable farming practices with sustainable agricultural intensification through innovations using technologies such as microbial-based fertilizers, plant growth-promoting bacteria and bioengineered crops tolerant to crops diseases.

Sustainable intensification of land use offers major opportunities to increase bioresource efficiency, reduce land used for food production and mitigate deforestation. Sustainable aquaculture will also play a key role in the future in contributing to sustainable food systems and to release pressure of overexploited resources. Modern biobased energy carriers replacing unsustainably harvested wood fuel can together with improved cooking stoves offer more efficient energy use and improved household air quality.

More efficient use of biomass, as described above, would also improve the prospects for land conservation and the preservation and restoration of degraded ecosystems. This offers new opportunities for a broader bio-tourism creating new jobs and rural livelihood opportunities. In an era of accelerating regional connectedness and integration, bio-tourism is one of the fastest developing industries in the region and an avenue through which the region can fast-track economic development.

4.13 A Summary SWOT analysis of bioeconomy development in the region

This section summarises the Strengths, Weaknesses, Opportunities and Threats (SWOT) for bioeconomy development in the region.

These provide the context in which a regional Bioeconomy Strategy is situated. These define the landscape in which this Regional Strategy (and ultimately, the national bioeconomy strategies that it will inspire) seeks to provide a framework for guiding biosciences R&D and innovation investments as part of the economic growth agenda of the region, integrating indigenous and scientific knowledge to add value to bioresources to stimulate the demand for biobased products and respond to that demand as a critical component of the economic growth agenda.

Strengths	Weaknesses
Rich biodiversity and bioresource production base. The East African economy is largely bio- and agro-based, with agriculture contributing on average 33% of the GDP. Africa has a large rural population including a large young easily trainable working population. Increasingly stronger universities, and research institutions and innovation and development capabilities, Increasingly supportive political environment (e.g., specialised innovation ministries, and agencies STI policies) Presence of Regional Institutions (IGAD, EAC, COMESA) that plays an important role for economic integration Undergoing infrastructure development in the region connecting countries (e.g., improving ports, roads, digital infrastructure, and planned railroads) which when ready, will facilitate regional communication and trade. Current trends for harmonisation of policies and strategies (e.g., this bioeconomy strategy) Countries in the region are improving the infrastructure for biobased economic growth, including agro-industrial parks, innovation hubs etc.	Low agricultural productivity due to factors such as lack of access to improved seeds and agricultural inputs, inadequate training, and extension services etc. Current Infrastructure in the region inadequate (roads, harbours, agricultural product storing facilities, energy supply etc. Weak linkages between academia and industry Inadequate financing resources, lack of venture capital to fund innovation and deployment. Inadequate infrastructural industrial capacity, and insufficient technology and human capacity for value addition to primary produce. Low level of industrial investments by both public and private sector and lack of capital and actors funding the movement of novel biobased products from early stages of innovation to the market. Low product quality, poor certification, accreditation of products, lack of quality control labs, etc. leading to poor competitiveness in global markets. Difficulties for small scale farmers processors and bio-entrepreneurs to meet regulatory requirements to access markets in developed countries (e.g., Global Gap certification). Weak IP systems within member states.
Opportunities	**Threats (External)**
Limited “lock in” investments in the fossil fuel economy. Opportunities to leapfrog into a circular biobased industrial base. Late comers may have an advantage in adapting new bioinnovations and biobased technologies Financing opportunities potentially for combatting climate change and replacing fossil fuel from global/multilateral funding institutions (e.g., GEF, the Green Fund). Increasingly growing, regionally inter-connected markets for bio-based products and services. East Africa may be an increasingly interesting market for international investors, B2B Collaboration. Good opportunities for increased use of renewable energy (geothermal, wind, hydro and solar) to support bioeconomy activities. Political good will and support for transformational development in the region.	Effects of climate change on bioresource productivity Non optimal use of biological resources causes degradation of ecosystems services (e.g., land degradation, deforestation, habitat destruction and loss of biodiversity). Political instability and conflicts due to increasing unemployment. Potential resource conflicts. International trade-tariff and non –tariff barriers restrictions. Emerging and re-emerging diseases (crop, animal, and human). High competition in the global market with established multinationals. Oil discoveries in the region (which may not make use of renewable biofuel and biobased material attractive).

5. Strategic Direction

Vision: *A vibrant, socially inclusive, and innovative bioeconomy contributing to sustainable economic growth and development in East Africa.*

Mission: *To catalyse and support innovative and sustainable use of bioresources as the major driver of inclusive economic growth and development in East Africa.*

Objective
The overall objective of this Strategy is to achieve *economic growth and job creation, making use of the region's bioresources to develop products and services while contributing to an improved environment and climate change mitigation.*

Specific Objectives
The overall objective will be achieved through:

i. Building and improving regional and international partnerships and collaboration, sharing knowledge, and building capacity for research, innovation, and entrepreneurship, including the development of PPPs and precompetitive collaborations.
ii. Promoting and strengthening regional trade, markets, and business cooperation for bioeconomy, including fostering opportunities for import substitution.
iii. A harmonised regional approach to mobilise the collective efforts of key stakeholders in the region, creating structures for innovation and deployment of technologies to operationalise the bioeconomy in East Africa
iv. Supporting the creation of technological and business environments in the region that encourage investment, making the region a bio-business attraction where start-ups and PPPs thrive – transforming East Africa's businesses through a shift to clean growth that maximises the share of the region's businesses in Africa's markets
v. Catalysing the development of national bioeconomy strategies, appropriate policies, and socioeconomic conditions to allow innovative and sustainable biobased products and services to thrive.
vi. Supporting and harmonising the improvement of necessary infrastructure for the bioeconomy (e.g., roads, harbours, storage facilities)
vii. Fostering an integration of indigenous and scientific knowledge to add value to bio-resources and meet the demand for bio-based products
viii. Joint monitoring and information sharing of bioeconomy development.

5.1 Strategic Thematic Areas

A combination of a comprehensive situational analysis of strengths, weaknesses, opportunities, and threats incorporating perspectives of key stakeholders have informed the strategic choices for this Regional Strategy. In addition, the strategic focus of the Strategy has been informed by a careful consideration of both what is needed and what is possible, while recognising that there are other potentially important areas within the bioeconomy that are not addressed here. While the Strategy is regional in its scope, it is recognised that implementation will be operationalised at country levels, but that regionally coordinated action will be required to achieve synergies and significant multiplier effects. Care has been taken to build on existing sectoral priorities (in sectors such food and agriculture, health, environment, and energy), not duplicating priorities therein, but rather complementing and

enriching these with priorities that are relevant from a bioeconomy perspective. It is recognised that there exists national (and for some, regional) strategic priorities that specifically address food security, health, environment, and energy. This Strategy provides a means to enhance the delivery of those strategic goals, but specifically leveraging on the use of bioresources across the sectors, and capitalising on the growing possibilities provided by the power of biosciences and innovation to optimise value creation from these resources while delivering a sustainable economy.

The priorities in this strategy are based on the functions, processes, and tools central to bioeconomy development. Four priority Strategic Thematic Areas (STAs) emerged from this analysis and relate directly to the Overall Objective of this Strategy.

The priority STAs are:

- *Food security and sustainable agriculture*
- *Health and well-being*
- *Bio-based Industrial Development*
- *Sustainable Energy*

The Key Result Areas (KRAs) within each of the four STAs are summarised in the sections below.

5.1.1 Strategic Thematic Area 1: Food security and sustainable agriculture

***Strategic Objective 1**: To introduce new biobased technologies and solutions to strengthen food and feed production, ensuring food security.*

Increasing agricultural productivity has for a long time been a central priority in many agricultural strategies and development plans for all the countries. Emerging technologies in modern bioeconomies – not least modern biosciences – provide an increasingly powerful innovation engine to support and enhance sustainable agricultural production.

KRA 1.1: Value addition to food crops, livestock, and microbial products

***Strategic Objective 1.1**: To deliver economic growth and create opportunities for smallholder farmers and SMEs by adding more value to primary produce and the use of agricultural residues*

Improving value addition to food crops, livestock and fish is a central priority in agricultural strategies and development plans of countries in the region. Successful value addition will be a major pull factor for agricultural production and productivity improvement already explicated in these strategies and plans. Currently value chains of major crops, livestock and fish, and algal produce in the region are mostly made up of small- to medium-sized, largely informal, private sector enterprises. The degree of value addition varies considerably between countries and types of primary produce. For example, while value addition to commercial crops such as coffee, tea, and sisal is substantial in the region, crops such as cassava, sorghum and millet undergo limited value addition. Emerging technologies in the modern bioeconomy - such as modern bioprocessing - provide an increasingly powerful innovation engine which the region will use to improve traditional and current agro-processing and value addition. In East Africa several value chains exist that have emerged in recent years. In Kenya a company has been working with croton (*Croton megalocarpus* Hutch.), an indigenous tree in East and Southern Africa whose seeds have been used to produce vinegar, fertiliser, poultry feed and oil for biodiesel in a sustainable form by collecting the fruits of trees planted on farms.

Another value chain in the region is the coconut. Tanzania produces over 400,000 tonnes of coconuts annually, while Kenya produces over 100,000 tonnes[18]. Around 750,000 households rely on the crop for income and food security. The potential value of the crop is estimated to be over 200M US$ in Kenya alone, but it is estimated that only 53% of the potential value is realised[19], with some estimates as low as 25%[20]. The many products including coconut wine, oil, roofing materials, broom and coconut wood. However, there is huge potential to further develop higher added value products such as face creams, milk powder etc. Tanzania currently produces 13,000 tonnes of coconut oil but there is potential to expand this to 58,000 tonnes based on the current production of coconuts. Production of oil results in a six-fold value addition compared to the value of the coconuts[21]. Many micro-enterprises are engaged in value addition, but the sector faces several hurdles. Nevertheless, there is a real opportunity to transform the coconut value chain into a sustainable and profitable industry. Upgrading the skills and knowledge base of producers and processors and the introduction of new technologies will greatly enhance the value of the subsector.

Box 2: Coastal and freshwater resources for the bioeconomy.

The shores of East Africa, with its bays, mangrove stands have many resources such as shells, crabs, seagrasses, seaweeds (algae), starfish, small fish, shrimps etc. Large fishery resources are in the rivers and in the many lakes of East Africa (e.g., Lake Victoria, Turkana, Tanganyika, and Kyoga).

The fish market in East Africa is estimated at 1,300 million tonnes and there is an estimated market for fish and fish products for Africa of US$24 billion. Job creation in the sector is estimated at a ratio of 1.4 to 3.5 onshore jobs for each fisherman. The average waste or by-product from the sector is around 600,000 cubic meters per year [22],[23],[24]. Around Lake Victoria the fish processing industries generate approximately 150,000 tonnes of waste with nearly 80% dumped and not utilised. The residues of fish filleting can however be used to make low-cost products with a high concentration of essential nutrients. For instance, in Uganda by-products from Nile perch (*Lates niloticus*) are used in development of different micro-nutrient fish powders that could be used to enrich diets. Fish skin, which today is considered as waste, can be processed into leather. In Kisumu about 70 tonnes of fish skin waste are reported to be generated weekly to make leather products for export[25]. This has the potential to boost leather production in the region, since African countries account for only 4% of world leather production and 3.3% of value addition in leather. Leather exports from Kenya in 2013 amounted to only US$140 million, which accounts for 0.14 % of the world's exports.

Potential impact: The potential in the region to add more value to primary produce is large for many food crops, livestock, and seafood produce. There is also high potential to use more

[18] FAOSTAT data.
[19] Nuts and Oil Crops Directorate. Coconut Value Chain Status Report, 2020.
[20] Mwachofi, H.P. 2016, Value chain analysis of the coconut subsector in Kenya. MSc Thesis, University of Nairobi.
[21] https://www.thecitizen.co.tz/tanzania/news/business/-time-tanzania-used-coconuts-to-boost-edible-oil-production-3554890
[22] Obiero K, et al. 2019. The Contribution of Fish to Food and Nutrition Security in East Africa: Emerging Trends and Future Outlooks. Sustainability 2019, 11(6), 1636; https://doi.org/10.3390/su11061636
[23] IPSOS, 2018. EAST AFRICA FISH MARKET ASSESSMENT Size, Sustainability and Opportunities for growth in Aquaculture: Kenya, Uganda, Tanzania, and Rwanda. STUDY REPORT. Kenya.
[24] The World Bank. 2020. Africa Program for Fisheries https://www.worldbank.org/en/programs/africa-program-for-fisheries
[25] Gumisiriza R et al. 2009. Nile perch fish processing waste along Lake Victoria in East Africa: Auditing and characterization. African Journal of Environmental Science and Technology Vol. 3 (1), pp. 013-020, January 2009. Available online at http://www.academicjournals.org/AJEST

agricultural residues, and processing by-products in new value chains, providing additional income to farmers and other value chain actors. One example is cassava, which can be processed into chips, flour and alcoholic beverage and biofuel production. Cassava waste can also be converted to useful products such as bioenergy bio-packaging materials, and biofertiliser.

KRA 1.2: Novel food and feed products

Strategic Objective 1.2*: To produce a variety of novel, safe and healthy food, and feed products for growing local, regional, and international markets*

The global market for novel functional foods, feeds and food/feed additives and nutraceuticals (foods with health-giving/medicinal benefits) are growing rapidly. Probiotic feed products also have a large potential in the region. With its large biodiversity and rapidly increasing demand for novel food products, the region seeks to build and develop an industry based on functional food derivatives from locally sourced bioresources. Such an industry will serve local, regional, and international markets. In addition, there is a growing global trend (especially in the OECD countries) to reduce traditional meat consumption to combat climate change, presenting a market for new sources of proteins, complementing the current animal protein production systems in the region. The region will pursue development and use of novel, resource-efficient protein production systems such as food and feed products from insects, algae, Spirulina (a type of cyanobacteria), molluscs, etc., replacing animal protein, especially from intensive production systems.

Box 3: Novel prebiotics from African plants.

Prebiotics are non-digestible food ingredients that increase populations of healthy bacteria in the gut, aid digestion and enhance the production of valuable vitamins. The global market for prebiotics is set to grow to well over US$9 billion in the next 5 years, with increasing use in both human and animal foods.

The most well-known prebiotic is inulin, mainly derived from the chicory root. However, several African plants also have potential as prebiotics. Yam (*Dioscorea*), is grown mainly in West African countries, but native species of yam have been identified in Kenya and Ethiopia[26]. Despite a lack of information on the structure and mechanism of action, yam is touted as a promising source for developing functional foods that can positively modulate gut microbiota. It contains several phytochemicals including biotin (Vitamin B7) that is crucial to the proliferation and maintenance of gut microbiota[27]. Another preliminary study also showed that orange fleshed sweet potato may have prebiotic potential. There is obviously considerable opportunity for further research and development to enable countries in the region to enter this lucrative and growing market.

Potential impact: The potential impact is huge. As an example, the global market for Spirulina alone is around US$400 million, with an annual growth rate of over 10%[28], while the market for carotenoids (which can be extracted from plants or algae) is over US$1.4 billion[29]. In the case of substitutes for meat protein, the global market is over US$4 billion, and is growing

[26] Wilkin, P. et al. 2009. Systemic Biology 34, 652-659.

[27] Isibor, P.O. et al. 2021. https://doi.org/10.1177/11779322211012697

[28] https://www.prnewswire.com/news-releases/the-global-spirulina-market-generated-346-million-in-2018--and-is-projected-to-reach-779-million-by-2026--growing-at-a-cagr-of-10-6-from-2019-to-2026--300957297.html

[29] Fortune Business Insights. https://www.fortunebusinessinsights.com/industry-reports/carotenoids-market-100180

exponentially[30]. In Africa, although the market for meat substitutes is growing from a low base, the annual growth rate is over 8%, only constrained by product availability. The region is well placed to enter markets of this nature, with a potentially very significant economic impact.

Box 4: The growing market for biopesticides in East Africa.

Both globally and across Africa in particular, there is a pressing need to develop cheaper, more environment-friendly alternatives to chemical pesticides. Biopesticides to protect agricultural crops are derived from plants and microorganisms, such as fungi, bacteria, and viruses. They are often much cheaper to develop than new synthetic pesticides. Farmers will however need training to use them, since biopesticides often are more complicated to use than synthetic pesticides, in terms of transportation, storage, mixing and application. Currently, global sales of biopesticides are estimated to be worth roughly US$4.4 billion[31], and constitute some 8% of the overall pesticide market with a growth rate of more than 15% per year. Due to the pressing need to produce more food more sustainably, preserving vital ecosystem services, global growth of bio-pesticide sales is projected to outpace that of chemical pesticides in the years to come. For these reasons, large global agrochemical companies have become involved in production and sales of biopesticides including in the East Africa market largely through acquisitions and licensing deals. There is also an increasing number of East African companies and institutions, such as ICIPE, engaged in developing biopesticides for the East African market, worth roughly US$400 million annually.

With a growing consumer demand for food free of pesticide residues in the lucrative EU export markets and in a growing regional African consumer market, there are significant opportunities for increased bio-pesticide production and use in the region. Such local production can, apart from supporting African farm productivity and sustainability, also benefit job creation and growth of local bio-pesticide companies as well as stimulating investments in local bio-pesticide production by international companies. Factors that would positively influence such a development, would be an increased awareness among African farmers on the potential benefits of biopesticides, more stringent quality control of bio-pesticide efficacy and certification standards at a regional level.

KRA 1.3: Biobased agricultural inputs

Strategic Objective 1.3*: To support and enhance sustainable agricultural production through the growth of bio-based agricultural inputs produced in the region.*

Crop and animal pests and diseases are a challenge for the region, holding back agricultural productivity and having a negative impact on livelihoods and nutritional status. The pest and disease pressure may also be aggravated by climate change impacts. Pesticides, insect-repellents, and fertilisers are mostly imported, represent a major cost for farmers, and are out of reach for many smallholders. Biopesticides, bio-fertilisers and growth enhancing microorganisms, and biocontrol agents based on organic and renewable resources represent a major opportunity for countries in the region. Additionally, they are generally much less toxic to humans and other mammals and have less impact on wildlife and the environment

[30] Allied Market Research. https://www.alliedmarketresearch.com/press-release/global-meat-substitute-market.html
[31] Fortune Business Insights. https://www.fortunebusinessinsights.com/industry-reports/biopesticides-market-100073

than conventional chemical inputs. However, research is needed to improve their efficacy and user friendliness. This KRA seeks to deliver locally made biobased solutions, which could promote agricultural productivity for smallholders, while also creating jobs. The region already has some enterprises in this domain at limited scales that can be built upon. To make this happen (see Chapter 6), interventions will be undertaken to ensure that a supportive regulatory and standards environment is developed, and to build capacity to support the use of these bio-based inputs.

Potential impact: The development and application of biobased agricultural inputs has potential to allow farmers and rural communities in the region to benefit from the valuable niche markets opening in developed countries for organically produced foods and increasing demand for residue free crop protection products. The lack of residues and the positive environmental and toxicological profile of biopesticides also make it much easier for African countries to export crops to countries using ISO and CODEX standards.

5.1.2 Strategic Thematic Area 2: Health and Wellbeing

***Strategic Objective 2**: To develop a biobased healthcare sector contributing towards a healthy population with improved wellbeing, addressing regional priorities and building on indigenous knowledge and practices.*

The East African region is largely dependent on imported products for diagnosis and treatment of major diseases impacting the health of both humans and animals. However, many diseases that are prevalent in the region, such as malaria, are not priorities for the large pharmaceutical companies. The emergence of the COVID-19 pandemic has highlighted the fragility of global supply chains and the need for the region to develop its own health solutions. This provides a major opportunity within the context of the bioeconomy, particularly harnessing traditional knowledge in the region to complement existing strategies.

KRA 2.1: Biobased pharmaceuticals
***Strategic Objective 2.1**: To strengthen research, development, and innovation capabilities in the region to screen for and manufacture active pharmaceutical ingredients, biopharmaceuticals, diagnostics, and vaccines targeting major diseases in the region.*

Due to a growing population, there will be an increased need for a secure supply of affordable drugs, diagnostics, vaccines, and medical devices to address major diseases in the region affecting both humans and livestock. There is an opportunity for the region to develop more drugs, vaccines, and other biologicals locally, based on locally sourced pharmaceutical ingredients. A biobased health sector, producing health products from local resources will generate jobs and economic growth at the same time as supporting public health goals. An example is bio-based polymers with anti-microbial properties that can be extracted from locally produced materials. A key result here will be to support and strengthen research, development, and innovation capabilities in the region to screen for and manufacture active pharmaceutical ingredients, biopharmaceuticals and vaccines targeting major diseases in the region. Establishment of advanced formulations expertise and modern drug delivery systems, and the necessary infrastructure, such as preclinical testing facilities, will be an important component of this KRA.

Potential impact: The pharmaceutical market size of the region is at least US$ 4 billion annually with a large volume spent on essential medicines, particularly antibiotics, anti-

malarias, anthelmintics, disinfectants, analgesics, and anti-retroviral medicines. The region currently imports 70-90% of its medicines, many from Asia with long lead times and risks of delays and supply failures, resulting from exporting countries priority policies, especially during epidemics and pandemics. The EAC already has a Regional Pharmaceutical Manufacturing Plan of Action that aims, *inter alia*, to decrease dependency on pharmaceutical imports to less than 50% and support the expansion of the product portfolio of EAC firms to cater for more than 90% of disease conditions. The focus of this KRA on biobased pharmaceuticals will complement and support ongoing efforts in this area, integrating local knowledge and bringing modern bioscience to bear on the health issues of the region. With proper regulatory harmonisation, countries will achieve faster lead times and more responsive local supply chains. This will support socio-economic development and have a major benefit in case of future disease outbreaks.

KRA 2.2: Indigenous knowledge and biobased traditional medicines
Strategic Objective 2.2*: To promote indigenous knowledge in traditional medicines through the identification of available biological resources in the region with verifiable and validated health benefits, and to understand the active ingredients involved.*

Traditional medicines and indigenous knowledge today play an essential role in maintaining health and well-being in the region. Innovative use of traditional medicines and indigenous knowledge would be an essential part of a modern health bioeconomy in the region. It also includes understanding the role of microbes and using products from these in keeping us healthy.

This is closely linked with KRA2.1 above, but a focus here is on Indigenous knowledge for the development of biobased traditional medicines and health products. This KRA will involve four main activity streams, thus: searching or 'bioprospecting' – at local/community levels to identify promising biological resources (e. g. plant species; fungi etc) conducting research on identified materials including safety and efficacy; developing commercial products; and working with rural people to develop skills and competencies for ensuring a pipeline of production where appropriate. In contrast to KRA2.1 where intellectual property (IP) management is based on conventional IP regimes, the IP management in KRA2.2 will be based on the Access and Benefit Sharing regimes, arrangements and principles laid out in the Nagoya protocol of the Biodiversity Convention ensuring that local communities benefit from any developments. Rigorous validation of traditional medicines and support to the indigenous knowledge system, support and advice on household medicinal gardens and the making of home remedy formulations will be important components of the health bioeconomy in the region. Countries in the region have made significant progress in the development of national policies, laws and regulations and national programmes for traditional medicines inspired by the WHO Traditional Medicine Strategy 2014–2023.

Potential impact: Although widely used in the region, there is little data on the safety and efficacy of most traditional medicines. Meanwhile, indigenous knowledge is rapidly disappearing as rapid modernisation causes the youth to be out of touch with their traditions and there is reduced inter-generational knowledge transfer. At the same time, medicinal plant resources are diminishing due to unsustainable harvesting practices and habitat destruction. A focused programme to harness indigenous knowledge and build an evidence-based system for validation of health and safety claims will have a significant impact on the health of the region's population.

Box 5: Developing biobased health products in East Africa.

While the conventional pharmaceutical market in the region has an annual turnover over of some 4 billion US$, the market size for pharmaceutical drugs based on traditional and indigenous knowledge is very difficult to estimate. However, traditional medicines using indigenous knowledge based on local biodiversity are often the primary source of affordable health care for well over half of the rural population in East Africa. The World Health Organisation has reported that traditional and complementary medicine (Including herbal medicine) can make a significant contribution to the goal of Universal Health Cover by being included in the provision of essential health services. Natural product extracts are frequently used as the basis for pharmaceutical research across the region's universities. However, studies rarely progress beyond academia even when the results are promising, partly due to a lack of adequate funding and poor links between academia and industry. The latter is addressed in the BioInnovate Africa, linking academia and industry to co-develop innovative and economically viable biobased technologies.

Within the BioInnovate Africa two innovation projects and consortia are focused on development of biobased health products. The first, focusing on malaria prevention, is led by University of Burundi developing low cost, highly efficient and innovative mosquito-repellent products, that can be used for mosquito net impregnation. The repellent is based on essential oils extracted from catnip and other locally produced plant species. The project is also developing appropriate farming methods for catnip production in the context of smallholder farming in East Africa. The other BioInnovate Africa project, led by the Kenya Agricultural and Livestock Research Organization, aims at improving the control of Tsetse flies transmitting trypanosomiasis in livestock and sleeping sickness in humans. In this project, still at pilot scale, tsetse fly repellents and attractants derived from waterbuck have shown incremental improvements relative to previously formulated blends and have large potential to control tsetse fly populations and disease infestations more efficiently in the region. The waterbuck compound blends are separately formulated and encapsulated on nanoparticles for controlled release and further incorporated in release devices protecting humans and livestock.

KRA 2.3: Bio-based cosmetics and well-being products
Strategic Objective 2.3*: To develop an African based personal care industry, based on local and regional bioresources and targeting expanding regional and international niche markets. Such production will be based on fair trade values while protecting and sustainably using the biodiversity of the region.*

With rapidly emerging markets in the region, there is increasing demand for consumer products such as cosmetics, well-being products such as vitamins and antioxidants, and cosmeceuticals (beauty products that contain beneficial active ingredients).The cosmetics, body care and fragrance markets are expanding globally, and with the fashion and cosmetics industry increasingly interested in basing their products on renewable, sustainably sourced raw materials, East Africa has the potential to use and add value to bioresources, such as shea butter, gum arabic, coconut oil, Aloe vera products, and neem tree products in order to move further up in the cosmetic industry value chain. Such production would be based on fair trade values while protecting and sustainably using the biodiversity of the region.

Potential impact: The overall African market for personal care products is estimated to be around US$ 12 billion, with the global market valued at US$400 billion annually[32]. The East Africa market is fast growing and is becoming increasingly attractive to global cosmetics companies. The development of local producers represents a potentially very large opportunity for the region and could have significant economic impact. An African based cosmetics industry basing its production on local bioresources could target local as well as expanding international niche markets. Such production could be based on fair trade values and sustainably sourced biomaterials protecting and sustainably using biodiversity of the region.

5.1.3 Strategic Thematic Area 3: Biobased Industrial Development

Strategic Objective 3: *To develop industries that stimulate sustainable economic growth and that add value to under-utilised renewable resources in the region.*

Growing recognition of the extremely high economic, political, and environmental costs of sustaining the fossil economy have opened the door for what has been referred to as the third (after health and agricultural biotechnology) revolution in biotechnology—industrial biotechnology. The region has an abundance of renewable resources, many of which are currently under-utilised, including crop and forest residues, marine and freshwater resources, niche organisms from extreme environments with valuable industrial properties etc. While remaining mindful of the need to avoid diverting agricultural production away from food production, there are many opportunities to develop industries based on these resources in the region.
Integral to the development of industrial biotechnology will be the development of biorefineries that provide multiple product and revenue streams. This also includes the transformation of traditional “agro-industries” such as sugar cane refineries, breweries etc, which today produce large amounts of unused waste, contributing to environmental pollution in the region. Products and processes that currently rely on non-renewable resources and chemical processes can be replaced with biologically based production platforms based on fermentation and other biological conversion platforms. New biorefineries and agro-industrial parks will produce a variety of biobased products, replacing imported products at competitive

[32] Global Market Insights. (2020). Compounding pharmacies market share | Statistics report 2026. https://www.gminsights.com/industry-analysis/compounding-pharmacies-market

prices. At the same time there are opportunities to develop smaller, community-based biorefineries.

KRA 3.1: Bio-based and biodegradable packaging materials
Strategic Objective 3.1*: To establish a manufacturing base for standardised bio-packaging materials, together with appropriate regulatory systems and infrastructure.*

Plastic pollution has been an increasingly severe problem in East Africa and in many countries the policy and regulatory responses have been extensive. At the same time there is an increasing demand for packaging material in the region that will reduce post-harvest losses, extending the shelf-life of food and consequently reducing food waste. E-commerce is also gaining grounds in Africa, requiring increasing amounts of packaging material. Thus, there are excellent opportunities for the countries in the region to replace environmentally polluting and fossil fuel-based plastics, imported to the region, with new bio-packaging material. A growing bio-packaging industry using biobased materials from renewable resources from the region, will generate jobs and incomes in the region as well as reducing postharvest losses.

Policies and regulations are important here. Several countries in the region, including Kenya, Rwanda and Tanzania now have plastic bag bans that has been shown to be effective in reducing the use of fossil fuel-based single use plastics.

Box 6: Bio-packaging and alternative non-plastic products.

Globally, the biodegradable packaging market is expected to grow from US$90 billion in 2019 to US$126 billion by 2025. The market value of plastic articles traded as packaging materials in East Africa between 2015 and 2019 was estimated at around US$700M (or around 480,000 tons), and the region has over 300 companies selling packaging material of which less than 80 are manufacturers.[33]

Many countries in the region have banned the use, manufacturing and import of plastic bags. These policies, mitigating climate change and limiting plastic waste have also provided opportunities and incentives for the use of biobased renewable material to be used to produce bags. This includes fabric-based bags, non-woven bags, pulp paper-based bags, woven bags (using sisal and cotton fibres) and recycled textile material. It also includes the novel production of bags made from cassava starch. These cassava bags are biodegradable within 6 months and approved by Kenya's National Environment Management Authority (NEMA). So far, cassava starch bags are imported from countries such as Indonesia. However, cassava is a major crop in the region and is a staple food in several countries, with an annual production of over 12 million tonnes. The bags could be produced locally from waste cassava peeling residues, which amount to over 3 million tonnes per year. Such alternative and complementary use of cassava produce would support profitability of cassava farming in the region, and create new jobs in an expanding East African bio-packaging sector[34]. Additional plastic bans in Kenya include cutlery, straws, PET-bottles, sweet wrappers, and other products containing petroleum-based polymers of which most can

[33] Mordor Intelligence. 2020. Biodegradable Packaging Market - Growth, Trends, Forecasts (2020 - 2025). https://www.mordorintelligence.com/industry-reports/gobal-biodegradable-packaging-solutions-market-industry
[34] Maulida, Siagian, M., & Tarigan, P. (2016). Production of starch based bioplastic from cassava peel reinforced with microcrystalline celllulose Avicel PH101 using Sorbitol as plasticizer. Journal of Physics: Conference Series, 710(1), 012012. https://doi.org/10.1088/1742-6596/710/1/012012

be substituted by biobased renewable materials including bamboo, wood, and crop residues. The global biodegradable cutlery market size was valued at US$40 million in 2018 and is expected to grow rapidly in the coming years, including in East Africa.

Potential impact: The packaging market in Africa is estimated to be growing at an annual rate of 8%. The market is driven by an expanding population of youthful consumers and increased demands for consumer products. This, combined with the demand for environmentally friendly packaging, opens considerable opportunities to develop new industries with associated job creation. Public procurement policies can also serve as a strategic intervention.

KRA 3.2: Bioprocessing enzymes
Strategic Objective 3.2*: To develop* enzymes for industrial applications *based on the region's microbial biodiversity.*

In East Africa, there is a large agro- and bio-processing sector producing products such as leather, textiles, beer, and food commodities, many of which are associated with environmental pollution. Enzymes or microorganisms today offer options for decreasing or avoiding environmental pollution and improving product quality and process efficiency. Thus, the availability of enzymes locally at an affordable price and with expert support on their use is expected to have a significant contribution in the region by lowering environmental pollution and by replacing several imported enzymes, chemicals, and processing aids.
Furthermore, because of the availability of unique habitats, such as alkaline environments, hot springs, etc with a large microbial diversity, the region could be, in the long term, highly competitive in the global industrial enzyme market.
In the last few decades, research conducted in different institutions in the region has produced isolated and characterised several novel microbial strains producing potentially attractive enzymes for industrial application. Given the importance of these enzymes in serving as processing aids in different industries in the region and their role in significantly reducing environmental pollution, scaling up of local production processes and use of the enzymes at industrial scale is strategic for the region.

Potential impact: Enzymes are used in a wide range of industries including pharmaceuticals, food processing, leather, detergents, paper and pulp and textiles. It is probably unrealistic to expect that industries in the region will be able to compete with large scale international producers of commodity enzymes, but there are opportunities in niche areas, and collaboration with multi-national players could bring mutual benefits.

KRA 3.3: Biobased construction materials
Strategic Objective 3.3*: To transform the local construction industry into one that is low-carbon and climate smart, based on locally produced renewable building materials.*

Demand for housing is increasing in the region due to urbanisation and a rapidly growing population. The region has the potential to leapfrog into low-carbon climate smart buildings, replacing imported concrete and steel with locally produced renewable building material. The construction industry in Europe and North America is already increasingly using renewable building materials, replacing concrete and steel, and hence reducing Greenhouse Gas emissions, and lower quality soft timber (such as bamboo/eucalyptus, etc.) is being processed into building materials which is equally as strong as steel and concrete.

An emerging technology with potential for the region is the use of fungal mycelium to create bricks and insulation materials. Moreover, the region has a diverse bio-resource base – e.g., gums, waxes, resins, and oils that also could be used by the building industry, for production of paint, solvent, and other building materials.

Potential impact: Cities and urban regions in East Africa become the home for thousands of new inhabitants every day, of whom many find themselves without housing. With that in mind, the massive need for new affordable and sustainable housing requires a significant building material sector which has the potential to be a major employer in the region. At present most construction materials are imported from China, but the COVID-19 crisis has exposed the fragility of this supply chain and the need to develop the local production.

Box 7: Using Bamboo for biobased industrial growth.

Bamboo is a giant grass, which grows naturally in East Africa, and covers more than 1.2 million hectares in the region. It is an important fast growing non-timber forest product and has for long been used as a construction material in the region due to its ready availability, ease of workability and its strength. In Ethiopia for instance, over 10 million Ethiopians are living in bamboo houses[35].

The renewed interest bamboo as a construction material has revitalised the utilisation of bamboo not only as a cheap renewable resource but also as a durable material with multiple uses and many value addition opportunities. In southern China for example, the bamboo industry has in many areas become a backbone for industry development and created economic growth and poverty alleviation in rural areas. With new technologies, bamboo fibres can serve as a source material for the rapidly growing global market of engineered bio-composite wood, where wood or grass fibres are mixed with various other biobased additives forming renewable, light and durable materials that can be made stronger than steel. Bio-composite material based on bamboo can thus be an important basis for biobased industries in the region, producing building material, furniture, biobased plastics, textiles, pulp for paper, green chemicals, and health products. It is also an important source for bioenergy and can be used carbonised and in chips, and several companies producing bamboo products exist in the region.

Bamboo is considered as one of the fastest growing plants on earth and under good management a hectare of bamboo planted by smallholders in the region could yield approximately 40 tons of raw bamboo fibre per year. Sustainable harvesting of bamboo and increased bamboo use can also help to reduce deforestation, contributing to climate change mitigation, improved soil conservation and mitigation of flood disasters.

[35] FAO. (2010). Global Forest Resources Assessment 2010. FAO Forestry Paper, 163, 350 pp. https://doi.org/ISBN 978-92-5-106654-6

KRA 3.4: Bio-based textile fibres

Strategic Objective 3.4*: To achieve a more productive and sustainable biobased fibre industry, complemented by the production of a range of textile fibres generated from local agro-waste materials.*

The high and increasing demand for textiles and clothing in the region, together with opportunities to complement cotton with other types of renewable fibres, opens new possibilities for an expanding sustainable textile industry. While cotton production and the associated processing and textile industry is already well established in the region, nevertheless there are substantial opportunities for improvement using all biowaste side-streams, optimising sustainability, and resource efficiency.
In addition, there is an increasing range of new textile biomaterials based on agro waste, which has become a valuable resource being reused into new materials, including such products as grape leather, a process that uses leftovers from wine industry to create vegetal leather; orange fibre made from citrus and orange rinds left over from juice production; yarn made from recycled coffee grounds; fish leather from tilapia skins; and viscose fibres from wood cellulose.

Potential impact: The EAC has recently approved a Cotton, Textiles and Apparel (CTA) Strategy encouraging procurement of institutional uniforms, beddings, and draperies by state bodies from the local textiles and fabrics industries. Member countries are also urged to develop strategies that will boost cotton production. Ethiopia and Kenya both have a growing garment production industry that is attracting inward investment. Exports of garments from the region amount to over US$700 million annually, but there is more than US$3000 million of imports[36]. Over 90 per cent of the material used is imported. This unbalanced trade shows the need to apply the CTA Strategy to improve the production in the region. This KRA offers great potential to support the CTA Strategy not only through the growth of cotton production, but also through the development of a more diversified and sustainable range of fibres for textile production.

KRA 3.5: Renewable bio-based oils

Strategic Objective 3.5*: To develop an industry based on sustainable production of renewable oils derived from the bioresources of the region.*

In industry there is an increasing demand for oils with special characteristics able to replace fossil oil-based products (as lubricants, or in green chemistry processes). East Africa is home to several oil crops, including tree crops (such as the croton tree), producing oils with attractive nutritional, health, and/or industrial characteristics. This KRA will focus on facilitating the development of a plant/tree-based oil industry, sourcing and developing local bioresources as well as sustainable production and use of known plants/crops such as palm, avocado, and citrus oil.

Potential impact: Sub-Saharan Africa currently produces less than 3% of global plant oils and is reliant on a growing level of imports (an estimated 9 million tonnes annually of sunflower, soybean, and palm oil). Tanzania alone imports 320,000 tonnes annually, despite it being the second largest sunflower seed producer on the continent. A focus on local production offers

[36] USAID. 2018. USAID East Africa Trade and Investment Hub Overview of the Cotton, Textile and Apparel Sectors in East Africa Region (Kenya, Uganda, Tanzania, Ethiopia, Madagascar and Mauritius) and Benchmarking with Sri Lanka and Bangladesh. East Africa Trade & Investment Hub. USA.

significant opportunities for import replacement, as well as export of specialised bio-based oils.

5.1.4 Strategic Thematic Area 4: Sustainable Energy

***Strategic Objective 4**: To increase the* production and use *of sustainable bioenergy and develop a range of bioenergy products for both household and industrial purposes.*

Bioenergy is energy for industrial or commercial use that is derived from biological sources (such as plant matter or animal waste). It includes energy from wood, wood waste, straw, manure, sugarcane, and many other by-products from a variety of agricultural processes that are currently under-utilised or utilised in an inefficient manner in the region.

Modern bioenergy is an important source of renewable energy. However, it is essential to ensure that crop production for biofuels does not impact on food production (the "food vs fuel" debate). Nevertheless, rural regions of East Africa offer significant opportunities for expansion of biomass production that can create value-added at low opportunity cost by improving degraded or poorly maintained lands. There is a high potential to use part of the crop and pastureland that are currently very inefficiently used for bioenergy purposes and at same time increase the productivity of existing agricultural production systems. The African Union and countries in East Africa are developing a Bioenergy Development Strategy and Investment Plan, and this Thematic Area supports its operationalisation. Activities under this STA will also be supported by the work conducted by the Global Bioenergy Partnership in Kenya and Ethiopia.

KRA 4.1: Biomass briquettes as alternative to charcoal and firewood
***Strategic Objective 4.1**: To promote initiatives in briquette production from waste materials to substantially reduce the unsustainable use of wood fuel.*

Firewood and charcoal alone provide more than 40% of energy used in Africa, and about 80% of households on the continent depend on wood and charcoal as a primary energy source. For example, the energy balance of Tanzania shows that petroleum and electricity account for only about 8% and 1.2%, respectively, with biomass use accounting for over 90% of energy consumption and continues to dominate as the main source of energy[37].

Biomass briquettes, mostly made from agroprocessing, agricultural and forestry residues, are increasingly popular in East Africa (and Africa generally) as an alternative fuel to charcoal and firewood, providing heat for cooking (and lighting). By turning organic waste into clean-burning biomass, use of briquettes helps save forests and biodiversity, and cuts greenhouse gas emissions. It also reduces the levels of indoor pollution in households which is responsible for deaths of an estimated 15,000 women and children annually in Kenya alone. There are already some factories in the region producing more than 2000 tonnes of briquettes a year from waste materials, but the potential is much greater than this. Work in this KRA will focus on scaling the production of biomass briquettes and improving and extending their industrial use, by refining the technology and developing the supply chain, together with development of improved cooking stoves. It will build on many on-going (but relatively small)

[37] IEA. 2019. Africa Energy Outlook 2019 World Energy Outlook Special Report. International Energy Agency Publications, 288. Retrieved from www.iea.org/t&c/

initiatives across the region[38].

Box 8: Briquettes and pellets as sustainable and modern energy carriers.
The East Africa region has large potential to produce modern bioenergy from a variety of biomass feedstock resources, including forest and agricultural residues, energy crops and the organic component of municipal solid waste. Briquettes and pellets produced from, agroprocessing, agricultural and forest residues such as sugar cane and pineapple bagasse, coffee, maize, and sawdust among others provide a more sustainable alternative to unsustainable firewood and charcoal production causing deforestation. Apart from being more efficient energy carriers, the use of briquettes and pellets also results in improved indoor air quality and human health. The technology used depends on the production scale, ranging from informal operations to large industrial operations. There is an average production of sawn wood in the region of around 970,000 cubic meters with an estimated 120,000 cubic meters of residues with potential use for briquettes and pellets or in combination with other agricultural or forest residues. Other material that is readily available is sugar cane bagasse. The average production of bagasse is around 5.5 million tonnes per year. The production of briquettes and pellets is still low in the region but could be expanded for use for the industrial market including the tea, coffee vegetable oil, and food processing sectors and other sectors that use boilers in their processes. The technology used depends on the production scale, ranging from informal operations to large industrial operations.

Potential impact: Tanzania alone uses one million tonnes of wood charcoal each year, resulting in unsustainable deforestation, so the regional market is huge for sustainably produced briquettes as an alternative. Small scale rural initiatives to produce briquettes could create employment for youth in rural areas where it is most needed and thereby reduce the migration into cities.

KRA 4.2: Production of biogas from organic waste

Strategic Objective 4.2*: To stimulate and support uptake of biogas technologies in the region at both household and industrial levels.*

Biogas is produced from anaerobic digestion of organic waste and consists primarily of methane and carbon dioxide. Small scale production of biogas from household digesters is growing in popularity in the region. The African Biogas Partnership Program (ABPP) has established a nascent industry for bio-digesters in Tanzania, Uganda, and Kenya. While the biogas is used for cooking, a secondary benefit is increased crop yields from the resulting bio-slurry. However, barriers still exist that hamper large scale dissemination, including high installation costs, inadequate user training, insufficient servicing, and inappropriate designs. Poor design choices, mainly due to overlooking the user energy needs and local conditions, contribute to the short lifespan of many installed biogas systems.

There are also opportunities to recover biogas at a larger scale from sources such as municipal waste systems, for electricity generation and for public transportation. By inserting a series of pipes into landfills at various depths, the biogas produced through natural

[38] UNEP. 2020. Sustainability Of Sugarcane Bagasse Briquettes And Charcoal Value Chains In Kenya http://www.globalbioenergy.org/programmeofwork/working-group-on-capacity-building-for-sustainable-bioenergy/activity-group-2/iki2-ethiopia-kenya/it/

decomposition can be collected and harnessed. While the potential for this is large, enhanced uptake requires incentives to be in place such as electricity feed-in tariffs and tax incentives. Furthermore, through innovation supported by scientific research, bio-hydrogen can be extracted from biogas and biomass and compressed into liquid hydrogen to be used as environmentally friendly biofuel.
This KRA will seek to further the growth of biogas production and utilisation at all scales to address the current barriers and reach more of the population in the region.

Potential impact: As a source of renewable energy, scaling biogas use will have a considerable contribution to reduction of greenhouse gas emissions and reduction in unsustainable use of wood fuels.

KRA 4.3: Advanced biofuels
Strategic Objective 4.3*: To support the development of biofuels produced from lignocellulosic materials and algae.*

Second generation biofuels are produced from non-food crops and agricultural and forest residues. In the case of some crops, such as sweet sorghum, there may be synergies with food production. For other lignocellulosic crops grown specifically for biofuel production, the choice of crop is important in avoiding conflicts in the supply of food, energy, and water. Nevertheless, rapidly emerging novel conversion technologies of forest and agroprocessing residues provides a great opportunity for future development of biofuels in the region. A wide range of conversion options is available, the most widespread being the production of liquid fuels (bioethanol and biodiesel) for transportation.

As a prospect for the longer term, biofuels are now being developed from microalgae. They are an ideal biofuel feedstock because of their rapid growth rate and greenhouse gas sequestration ability (net zero emission balance). They also do not compete with food or feed crops and can be grown on non-arable land and saline water. Technologies for their production and harvesting are still under development but offer future promise. Work in this KRA will focus on developing and implementing small scale second and third generation technologies that are financially viable and can be implemented at community level.

Potential impact: To date, there has been very limited production of advanced biofuels in the region, in part due to high capital costs and land tenure issues. However, in the longer term, small scale rural production offers opportunities for job creation for young people.

6. Key Strategic Enabling Actions

Strategic enabling actions are required to help translate the strategic intentions in Chapter 5 into programmes, and ultimately into outcomes and impacts.

The key enablers for successful delivery of the East Africa Bioeconomy Strategy will include: a) enabling policy environment ensured by enacting and harmonising policies and legislation in the region to support biosciences training and research, bio-innovation, and bio-businesses; b) enhancing the bioeconomy innovation system including facilitating the connection of entrepreneurs, especially start-up businesses, to affordable financing; c) capacity development in all areas of the bioeconomy; d) catalysing relevant and productive partnerships and collaborations to drive bio-innovations and bio-businesses, and e) effective