



UNIVERSITY OF NAIROBI

EMERGING TECHNOLOGIES IN KENYA – A LANDSCAPE ANALYSIS

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EMERGING TECHNOLOGIES IN KENYA: A LANDSCAPE ANALYSIS

2022

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Acronyms and Abbreviations

4G	Fourth Generation	ILRI	International Livestock Research Institute
4IR	Fourth Industrial Revolution	IoT	Internet of Things
ABI	Agri Business Incubation	IPR	Institute of Primate Research
ADC	Africa Development Centre	JKUAT	Jomo Kenyatta University of Agriculture and Technology
AgNPS	Silver Nanoparticles	JOOUST	Jaramongi Odinga Oginga University of Science and Technology
AI	Artificial Intelligence	KALRO	Kenya Agricultural and Livestock Research Organization
AIDs	Acquired Immunodeficiency Syndrome	KCAA	Kenya Civil Aviation Authority
AML-CFT	Anti Money Laundering and Combating Financing of Terrorism	KCAU	Kenya College of Accountancy University
AMREF	Africa Medical and Research Foundation	KCB	Kenya Commercial Bank
CA	Communication Authority of Kenya	KCPE	Kenya Certificate of Primary Education
CAK	Competition Authority of Kenya	KCSAP	Kenya Climate Smart Agricultural Project
CBK	Central Bank of Kenya	KEFRI	Kenya Forestry Research Institute
CUE	Commission of University Education	KEMRI	Kenya Medical Research Institute
DCP	Digital Credit Providers	KENIA	Kenya National Innovation Agency
DeHUB	DeKUT Innovation Hub	KEPHIS	Kenya Plant Health Inspectorate
DeKUT	Dedan Kimathi University of Technology	KEVEVAPI	Kenya Veterinary Vaccines Production Institute
DNA	DeoxyriboNucleic Acid	KHMIS	Kenya Health Management Information System
ET	Emerging Technology	KIPI	Kenya Intellectual Property Institute
ETs	Emerging Technologies	KoTDA	Konza Technopolis Development Authority
FCDO	Foreign Commonwealth and Development Office	KU	Kenyatta University
FDI	Foreign Direct Investment	LPG	Liquefied Petroleum Gas
FINTAK	FinTech Association of Kenya	MADC	Microsoft Africa Development Centre
GDP	Gross Domestic Product	MDAs	Ministries, Departments and Agencies
GIS	Geographic Information System	MKU	Mt. Kenya University
GIZ	German Agency for International Cooperation	MMUST	Masinde Muliro University of Science and Technology
GM	Genetically Modified	MU	Maseno University
GMOs	Genetically Modified Organisms	MUST	Meru University of Science and Technology
GPS	Global Positioning System	NACOSTI	National Commission for Science, Technology and Innovation
GSMA	Groupe Speciale Mobile Association	NBA	National Biosafety Authority
HIV	Human Immunodeficiency Virus	NCST	National Council for Science and Technology
IBC	Incubation Business Centre	NDW	National Data Warehouse
IBM	International Business Machines	NIIMS	National Integrated Identity Management System
ICGEB	International Centre for Genetic Engineering and Biotechnology	NIS	National Innovation System
ICIPE	International Centre of Insect Physiology and Ecology	NRF	National Research Fund
ICRAF	International Council for Research in Agroforestry		
ICT	Information and Communications Technology		
IIoT	Industrial IoT		
IITA	International Institute of Tropical Agriculture		

ODPC	Office of the Data Protection Commissioner	TUM	Technical University of Mombasa
OECD	Organisation of Economic Cooperation and Development	UAS	Unmanned Aircraft (or Aerial) Systems
OER	Open Educational Resources	UEAB	University of East Africa Baraton
PhD	Doctor of Philosophy	UK	United Kingdom
RTI	Research Triangle Institute	UNEP-CBD	United Nations Environment Programme - Convention on Biological Diversity
SANi	South Africa Nanotechnology initiative	UNIDO	United Nations Industrial Development Organization
SBBRA	Society for Biomedical and Biotechnology Research Africa	UoE	University of Eldoret
SEKU	South Eastern Kenya University	UoN	University of Nairobi
SME	Small and Medium Enterprise	US	United States
SMS	Short Message Service	USAID	United states and International Development
STI	Science, Technology and Innovation	USDA	United States Department of Agriculture
STL	Standard Triangle Language	YEDF	Youth Enterprise Development Fund
STP	Shielded Twisted Pair		
TUK	Technical University of Kenya		

Executive Summary

Emerging technologies (ETs) have been transformative around the world, and Kenya has not been left behind. Indeed, ETs have enabled Kenya to leapfrog legacy infrastructure systems, generate economic growth and promote social inclusion for citizens. There are numerous definitions of what constitutes an Emerging Technology (ET). This study adopts the definition by Rotolo and Martin who defined ET “as a radically novel and relatively fast-growing technology characterised by a certain degree of coherence persisting over time and with potential to exert a considerable impact on the socio-economic domain(s) which is observed in terms of the composition of actors, institutions and patterns of interactions among those, along with the associated knowledge production processes. Its most prominent impact, however, lies in the future and so at the emergence phase is still somewhat uncertain and ambiguous.”¹

This report presents the results of a study that sought to gain a deep understanding of the emerging technology ecosystem in Kenya. It encompassed an investigation into the landscape and context, enabling factors, risks, opportunities, and early precedents being set on use cases, governance, and the enabling (or not) environment. The overall objective of the study was achieved through the following two specific objectives: 1) to provide an in-depth analysis of the ETs landscape in Kenya; and 2) to identify the key gaps in ETs and recommend opportunities for bilateral and/or multi-lateral partnerships between Kenya, South Africa and the UK.

Both objectives were achieved using a five-dimension maturity model of the ETs ecosystem in Kenya. Three stages of maturity were defined – **ideation**, **nascent**, and **growing**. The characteristics of the three stages of maturity were based on five fundamental activities, namely **education**, **research**, **end-use**, **linkages** and **implementation**. The model formed the basis for analysis and determination of the stage of maturity of the collective and the individual ETs ecosystems.

The study identified seven primary ETs in Kenya’s landscape, namely, **artificial intelligence (AI)**,

blockchain, **internet of things (IoT)**, **big data/data analytics**, **geographic information systems (GIS)**, **biotechnology**, and **nanotechnology**. The identified ETs impact on several sectors of the economy primarily **agriculture**, **education**, **financial services/business**, **health**, **information, communication and technology (ICT)** and **water and sanitation**. The key actors were categorised by the role they play within the five fundamental activities.

Regulating ET remains a complex phenomenon given the need to mitigate associated risks while at the same time promoting innovation and maximizing benefits for all. For emerging digital technologies, for example, the Government is following an approach that takes into consideration how best to protect citizens, ensure fair markets, and enforce regulations while at the same time enabling the technologies and businesses to thrive. The approach is one of:² *Adaptive regulation* - Shift from “regulate and forget” to a responsive, interactive approach; *Regulatory sandboxes* - Prototype and test new approaches by creating sandboxes and accelerators; *Outcome-based regulation* - Focus on results and performance rather than form; *Risk-weighted regulation* - Move from one-size-fits-all regulation to a data-driven, segmented approach; and *Collaborative regulation* - Align regulation nationally and internationally by engaging a broader set of players across the ecosystem.

Overall, the ETs ecosystem in Kenya was found to be between the **nascent and growth stage of maturity**, based on the analysis of each of the fundamental activities and the roles played by each of the actors. Looking at each of the fundamental activities, the **education and linkages dimensions was found to be at the nascent stage of maturity**.

The ET ecosystems were further analysed as three distinct ecosystems – biotechnology, nanotechnology, and emerging digital technologies (AI, IoT, blockchain, big data/data analytics and GIS). The gaps identified at this level also provided for specific areas of potential collaboration between Kenya, South Africa and the UK at each of the fundamental activities within the three distinct ecosystems.

¹ Rotolo, D. and Martin, B. What is an emerging Technology, *Research Policy* December 2015.

² Ministry of ICT (2019)

Broadly, the key potential areas of collaboration in ETs are in capacity building, Joint research programs, technology transfer, innovation and policy accelerator programs, and academia-business community forums.

1. Overview of the Emerging Technologies Landscape in Kenya

1.1 Introduction

Across the globe, the rigorous revolution in almost all facets of life driven by emerging technologies is growing at a remarkable rate and is quite inevitable. The transformational nature of these technologies manifests in economies through enhanced transparency, efficiency, inclusivity, better decision making processes and service delivery.

Over time, Kenya's technological and innovation track record has remained impressive. In the 2021 Global Innovation Index, Kenya was ranked the second most innovative country in the Sub-Saharan Africa and was among the four developing economies with a record of over-performing on innovation relative to their development for the 11th year in a row. Notably, emerging technologies have allowed the country to leapfrog legacy infrastructure systems, generate economic growth and promote social inclusion for citizens. Indeed, Kenya's willingness to embrace innovation in partnership with the private sector has earned her the moniker of 'Africa's Silicon Savannah'.

There are numerous definitions of what constitutes emerging technologies in the literature. For example, Martin³ defined 'a "generic emerging technology" ... as a technology of exploitation that yields benefits for a wide range of sectors of the economy and/or society'. (65) Hung and Chu⁴ defined them as, '... the core technologies, which have not yet demonstrated potential for changing the basis of competition.' (104). Seeking to add more clarity, Stahl defined emerging technologies '... as those technologies that have the potential to gain social relevance within the next 10 to 15 years. This means that they are currently at an early stage of their development process ... they have already moved beyond the purely conceptual stage ... [but] are not yet clearly defined.' (3-4). These sample definitions and others collectively yield five key consensus attributes of emerging technologies namely: (a) radical novelty, (b) relatively fast growth, (c) coherence, (d) prominent impact, and

(e) uncertainty and ambiguity,⁵ from which Rotolo and Martin provide a definition that shall inform this study.

Emerging Technologies Definition: "as a **radically novel** and **relatively fast-growing** technology characterised by a certain **degree of coherence persisting over time** and with the potential to exert a considerable **impact on the socio-economic domain(s)** which is observed in terms of the composition of actors, institutions and patterns of interactions among those, along with the associated knowledge production processes. Its most prominent impact, however, lies in the future and so in the emergence phase is still somewhat **uncertain and ambiguous**."⁶

1.2 Study Objectives

This report presents the findings of a study that sought to gain a deep understanding of the emerging technology ecosystem in Kenya. This included an investigation of the emerging technology context, enabling factors, risks, opportunities, and early precedents being set on use cases, governance, and the enabling (or not) environment. The overall objective of the study was achieved through the following two specific objectives:

- i) To conduct an in-depth analysis of the emerging technologies landscape in Kenya with a view of maximising development impact; and
- ii) To identify the main gaps in emerging technologies and recommend opportunities for bi-lateral and/or multi-lateral partnerships between Kenya, South Africa and the UK.

The realisation of the two objectives was achieved through a process of collecting and analysing data to respond to key questions that were based on specific thematic areas. These included the definition/status/types of Emerging Technologies

³ Martin (1995).

⁴ Hung and Chu (2006).

⁵ Cozzens et al (2010), Rotolo and Martin (2015).

⁶ Rotolo, D. and Martin, B. What is an emerging Technology, *Research Policy* December 2015.

(ETs), the key actors, the impact and level of investment in ET; the role of regional organisations on ETs; the factors supporting or hindering the growth of ETs; the existing policies, regulations and standards on implementation, and the future projections and risks associated with the implementation of the ETs. The set of key questions that guided the study are summarized in Figure 1.1.

Objective and Key Questions; (b) Literature Search; (c) Literature Screening; (d) Quality Assessment and Data Extraction, and (e) Data Analysis and Synthesis.

The governance frameworks, embodied in policies, laws, and regulations relevant to ETs and arising from the literature review, were identified and synthesized providing an overview of the regulatory and policy environment for ETs in Kenya. A detailed stakeholder mapping of the key actors involved in the different

1.3 Methodology

The study methodology involved an in-depth literature review; a review of the policy and regulatory environment; stakeholder engagement through interviews/surveys, and a maturity assessment of the emerging technologies ecosystem. The literature review followed a multi-vocal systematic approach⁷ that focused on both peer-reviewed academic articles and grey literature covering the development and use of ETs in Kenya. The grey literature reviewed focussed on reports, trade journal and technical articles, books and book chapters. The approach, widely used in the literature⁸ and summarised in Figure 1.2, consists of five sequential phases: (a) The

ETs in the country was also performed. Majority of the stakeholders were identified through the literature and governance frameworks review, while others were identified through a snowball process with identified experts in different fields. Insights were also obtained through questionnaires and interviews with select key actors including researchers, practitioners, policymakers and funders. Their views were sought on a wide range of issues including the trajectory of the different ETs and their potential impact on the economy, the effectiveness and efficiency of the current governance frameworks, and areas of mutually beneficial outcomes from cooperation between Kenya, South Africa and the UK.

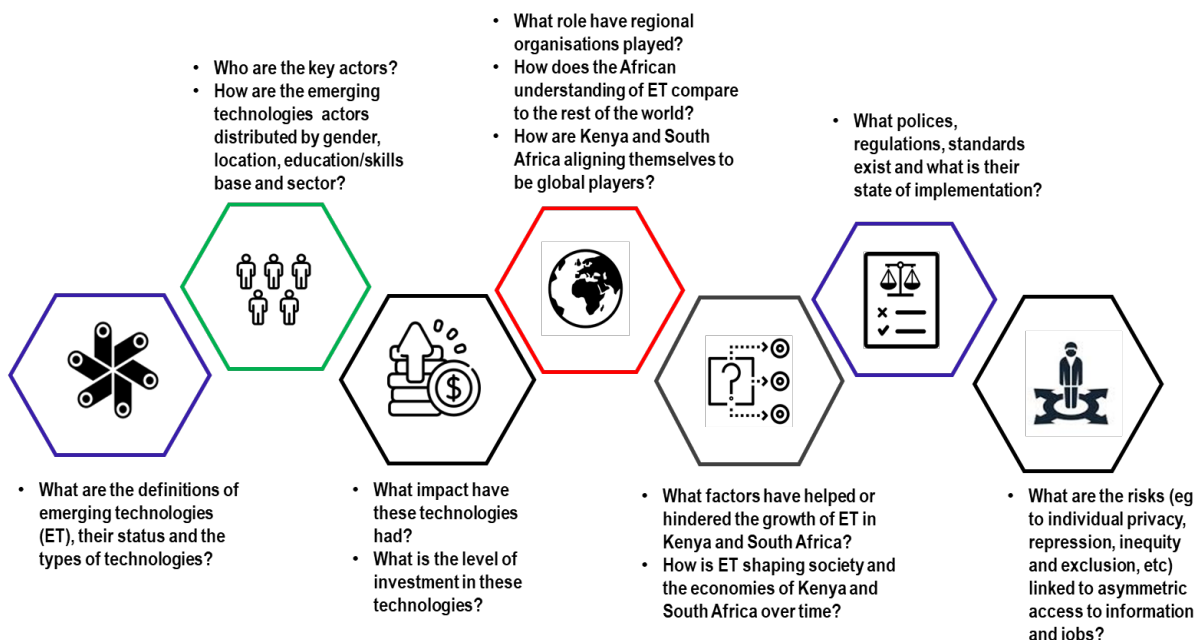


Figure 1.1: Key questions for in-depth analysis of emerging technologies landscape in Kenya

⁷ Ogawa and Malen (1991); Garousi, Felderer, and Mantyla, (2016).

⁸ Tripathi et al. (2018); Templier and Pare (2015).

The assessment using an ecosystem maturity model of the ETs landscape utilised the data and information collected from the literature review, review of governance frameworks, and stakeholder mapping and interviews/surveys. Perspectives on the ETs landscape, including the challenges, policy and regulatory reforms, etc., were triangulated from the multiple sources (literature review, policy review and stakeholder interviews) and multiple perspectives (researchers, practitioners, policymakers, and funders). The approach strengthens the evidence provided and gives a more holistic perspective of the ETs landscape.

1.3.1 Maturity Model of the Emerging Technology Ecosystem

An ecosystem maturity model was developed to form the basis for the assessment of the emerging technology ecosystem both individually and collectively. It enabled the study team to answer the following questions: What impact has the ETs had on the economy? What is the level of investment in these technologies? How is Kenya aligning itself to be a global player in the technology space? How are these ETs shaping the Kenyan society overtime? What factors have supported or hindered growth of ETs in Kenya? What are the main gaps in the ETs?

The system-level model provides an understanding as to how “fundamental activities of the innovation process are organised, distributed and coordinated.”⁹

The framework is based on *five fundamental activities*; research (basic developmental, engineering), implementation (manufacturing, deployment), end-use (customers of the product or process), linkage (bringing together complementary knowledge), and education (see Table 1.1).¹⁰ The model includes primary actors, secondary actors, and institutions as key elements of the innovation system, and are categorised based on their relationship with the five fundamental activities and with each other.

The stage of maturity or the development stage models of an ecosystem serve to provide tools for assessment of where an ecosystem is in its life cycle. It provides insights into the current level of success factors that have been recognised to be essential for the maturity, health, and sustainability of the ecosystem. This study employed the five fundamental activities and their attendant primary and secondary actors as the basis for analysis of the development stage or maturity level of the ecosystem. The selected indicators are presented in Table 1.2. Measurement, however, was a challenge as the data is not readily available. A survey of primary and secondary actors, grouped as researchers, start-up/businesses, policymakers, and funders, was therefore conducted. A copy of the surveys is provided in Appendix C.

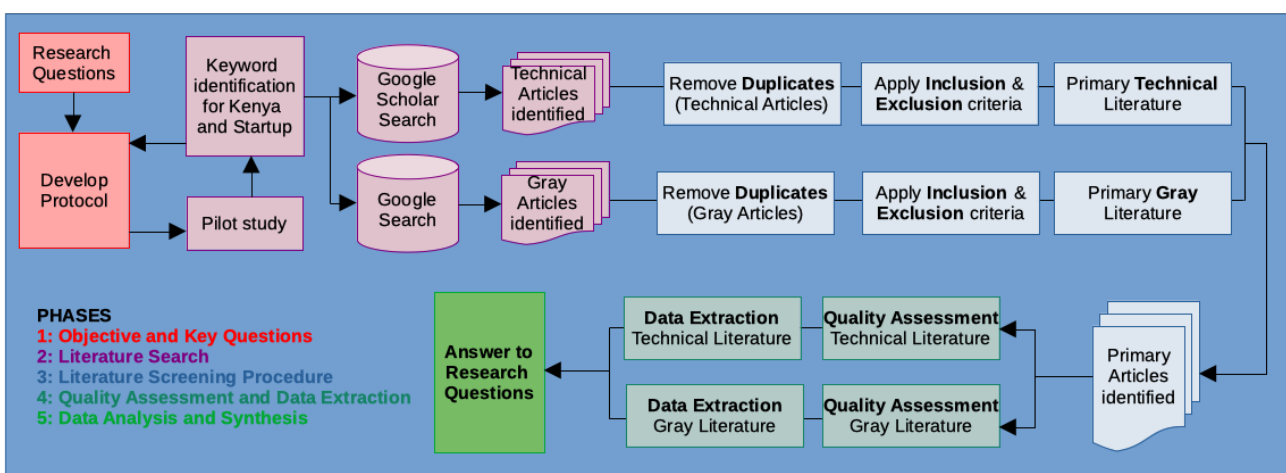


Figure 1.2: Systematic Multi-Vocal Literature Review Process

⁹ Liu and White (2001, p 1094)

¹⁰ Ibid

Fundamental Activities	Primary Actors	Secondary Actors
<i>Education</i> (knowledge and graduates)	Organisations that perform one or more of the five fundamental activities.	Organisations that affect the behaviour of or the action between primary actors. Can be direct (e.g. through mandates, regulations) or indirect (e.g. through policies, incentives.)
<i>Research</i> (basic, developmental and engineering)		
<i>Implementation</i> (production and commercialisation)		Institutions
<i>End-Use</i> (customers of the product or process outputs)		These are a set of practices, rules or organisation that guides or constrains and actor's behaviour.
<i>Linkages</i> (bringing together complementary knowledge)		

Table 1.1: Classification of actors in the innovation system in fundamental activities Model¹¹

Fundamental Activities	Potential Indicators
Education	Quality of graduates (measured by quality or availability of hires), New Masters and PhDs, university post-graduate programmes, researchers/professionals engaged in R&D, Africa/global ranking of universities with post-graduate relevant programmes, policies.
Research	Related Publications, R&D projects, patents, availability of funding for R&D, pilot projects, availability of required equipment, policies.
End use	Government targets, industry targets, demand from government, demand/opportunities in the market, demand/opportunities beyond the borders, policies.
Linkages	Technology dedicated workshops and conferences, network size, network intensity, collaboration with academia (or with private sector).
Implementation	New entrants, diversification activities of incumbents; availability of funding (traditional, equity, venture capitalists, angel investors), interest groups, policies.

Table 1.2: Indicators of maturity of fundamental activities

Three developmental stages of maturity are identified as ideation, nascent and growth. From the definition of ETs as being “radically novel” and “relatively fast growing”, whose emergent phase is “uncertain and ambiguous”, it is not practical to talk about a mature

development stage (the end point in typical ecosystem analysis) as when an ET ecosystem reaches the mature development stage, since the technology will no longer be considered emerging.

¹¹ Developed from Liu and White (2001)

Stage I: Ideation. This stage is mainly characterised by Research and Development (R&D) activities with pilots and proof-of-concepts on potential commercial applications. It is beyond basic research on fundamental principles.

Stage II: Nascent. This stage embodies the very early stages of the ecosystem development and formation. Its characteristics include extreme ambiguity driven by uncertainties in technology, competition, structures and demands. Commercial ventures are formed at this stage and sales begun.

Stage III: Growing. At this stage, the commercial applications of the technology start gaining strong acceptance in the market with increased demand and new entrants. Also, the ecosystem governance structures start becoming clearer.

The characteristics of each of the above stages based on the indicators presented in Table 1.2, are listed in Table 1.3. They formed the basis of the analysis and determination of the stage of maturity of the collective and individual ETs ecosystems. The analysis provided insights into potential opportunities for collaboration between Kenya, South Africa, and the UK. A detailed description of the model is presented in Appendix A.

1.4 Emerging Technologies and the Fourth Industrial Revolution

The Fourth Industrial Revolution (4IR) is “characterized by a fusion of technologies that is blurring the lines between the physical, digital and biological spheres.”¹² This has created opportunities for emerging technology breakthroughs in Artificial Intelligence (AI), robotics, big data/data analytics, Internet of Things (IoT), autonomous vehicles, Three Dimensional (3D) printing, nanotechnology, biotechnology, material science, energy storage, and quantum computing.

Driven by emerging technologies, 4IR is transforming various sectors. For example, in manufacturing, productivity and efficiency of processes are maximized by smart factories, which have highly connected and optimized cyber-physical system that is enabled by the Industrial Internet of Things (IIoT)¹³. Robotics is applied in industries in different ways. For

¹² Klaus Schwab, 2016

<https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/>

example, industrial robots are used in place of humans to handle heavy manufacturing tasks that may be dangerous and require more strength. On the other hand, collaborative robots, also known as cobots are deployed to work alongside humans to provide assistive capabilities such as lifting and assembling light materials¹⁴. Big data and data analytics are applied in industries for discrete event simulation programs.

Application of 3D printing technology on an industrial scale has enhanced additive manufacturing, which is a computer-aided production process that uses layer-by-layer addition of material(s). In healthcare, 3D printing is applied in fabrication of learning and anatomical replicas to enhance the diagnosis of illnesses, clarify treatment decisions, plan, and in some cases, practice chosen surgical interventions in advance of the actual treatments. 3D printing is applied in orthopaedic implants, prostheses, making hearing aids and dentistry¹⁵.

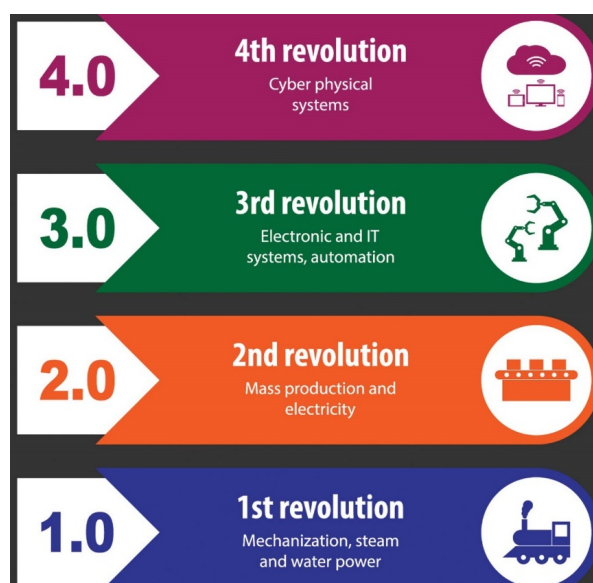


Figure 1.3 The Fourth Industrial Revolution (4IR)

¹³ Bansal (2019) <https://www.weforum.org/agenda/2019/06/connectivity-is-driving-a-revolution-in-manufacturing/>

¹⁴ Monivisal (2020) https://cd-center.org/wp-content/uploads/2020/05/P127_20200520_V2IS8.pdf, Emerging Technologies of the Fourth Industrial Revolution

¹⁵ Dodziuk (2016) Applications of 3D printing in healthcare, <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5071603/pdf/KITP-13-28425.pdf>






Fundamental Activities	Stages		
	Ideation	Nascent	Growth
 <p>Education</p>	<ul style="list-style-type: none"> • Few Masters and PhDs • Small number of academic departments, • Small number of researchers engaged in related research 	<ul style="list-style-type: none"> • Increased number of Masters and PhDs, • Small number of academic departments • Increasing number of researchers engaged in related research 	<ul style="list-style-type: none"> • Large number of Masters and PhDs, • Increased number of academic departments, • Increasing number of researchers engaged in related research
 <p>Research</p>	<ul style="list-style-type: none"> • Few or no patents, • Small number of publications, • Few pilot projects, • Low research funding, • Few policies supporting related research 	<ul style="list-style-type: none"> • Increased number of patents, • increased number of publications, • Increased number of pilot projects, • Moderate research funding, • Strengthened policies supporting related research 	<ul style="list-style-type: none"> • Increased number of patents, • Large number of publications, • Large number of pilot projects, • Adequate research funding • Strengthened policies supporting related research
 <p>End use</p>	<ul style="list-style-type: none"> • Insufficient demand and information for potential products and services, market size 	<ul style="list-style-type: none"> • Better understanding of and increasing demand for potential products and services, market size 	<ul style="list-style-type: none"> • Good understanding of and robust demand for potential products and services, market size
 <p>Linkages</p>	<ul style="list-style-type: none"> • None or few international connections (research) • Few linkages • No clusters. 	<ul style="list-style-type: none"> • Small number of international connections (research and business) • Small number of linkages • A few clusters. 	<ul style="list-style-type: none"> • Moderate international connections (research and business) • Moderate linkages • Moderate clustering
 <p>Implementation</p>	<ul style="list-style-type: none"> • No/negligible active start-ups or existing businesses who have diversified into the ET space; 	<ul style="list-style-type: none"> • A few active start-ups or existing businesses who have diversified into the ETs space but are in the early stages; • None or very few start-ups exist • Establishment of governance framework • Gaps in financing 	<ul style="list-style-type: none"> • Moderate number of active start-ups or existing businesses who have diversified into the ETs space, • Moderate number of scale ups • Facilitative governance framework • Increasing private sector financing

Table 1.3: Stages of Maturity in the Emerging Technology Ecosystem

2. Findings and Discussion

2.1 Introduction

This section presents the study findings and discussions on the identified seven primary ETs in Kenya’s landscape, namely, **AI, blockchain, IoT, big data/data analytics, Geographic Information Systems (GIS), biotechnology and nanotechnology**. The seven ETs were identified through in-depth literature review; a review of the policy and regulatory environment; stakeholder mapping and interviews/surveys. The presentations comprise of both qualitative and quantitative findings on the actors, governance, linkages and funding among other variables of analysis.

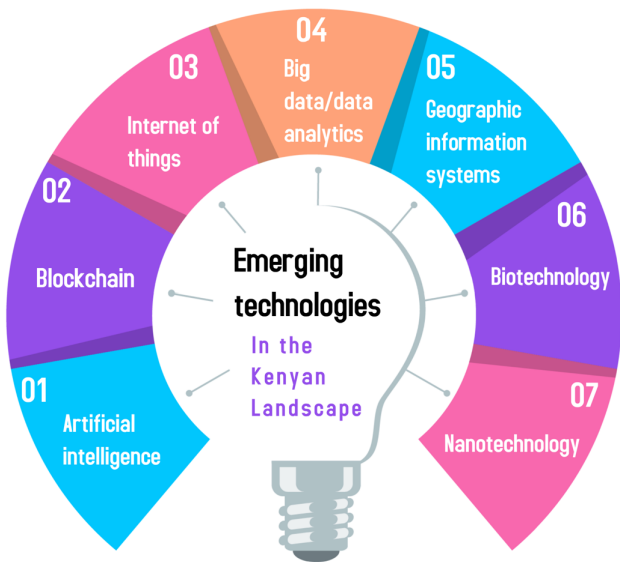


Figure 2.1: Emerging Technology Kenyan Landscape

2.2 Kenya’s Emerging Technologies Ecosystem

Emerging technologies are generated from research, continuous industrial development programs, or from individual innovative and entrepreneurial initiatives. The identified seven primary ETs in Kenya’s landscape impact on several sectors of the economy primarily **agriculture, education, financial services/business, health, Information, Communication and Technology (ICT) and water and sanitation**. These have been collectively discussed based on the key actors previously

defined. Subsequent sections delve into the analysis of biotechnology, nanotechnology, digital emerging technologies, and GIS ecosystems.

2.2.1 Key Actors

The key primary (academic and research community, private sector, not-for-profit organizations, Small and Medium Enterprises (SMEs) and other beneficiary organizations) and secondary actors (government, investors/funders, development partners) and their roles in the ET ecosystem in Kenya are summarised in Table 2.1.

2.2.1.1 Primary: Education

University education is essential in monitoring and assessment of global developments in the different ETs, and assimilation, development and implementation of the new paradigms locally.¹⁶ Universities also provide the ET ecosystem with a continuous stream of new knowledge (e.g. publications and patents) and new carriers of knowledge (post-graduate students)¹⁷. They generate “qualified personnel (in the emerging technologies) who can monitor technological and other trends, assess their relevance to the prospects of the country and individual firms, and help to develop responsive strategies while taking advantage of the trends.”¹⁸ A review of the undergraduate and postgraduate programmes encompassing the identified ET reveals that out of 63 universities accredited by the Commission for University Education (CUE), only 21 (33%) offer post-graduate programmes (masters and PhD) covering any of the ETs. With these, there is great disparity across the different ETs as shown in Figure 2.2 where biotechnology related post-graduate programmes are offered at thirteen universities (21%) on the top of the spectrum, with GIS at the bottom with only four universities (6%) offering related post-graduate programmes.¹⁹ The level of skilled personnel at post-graduate level may not, therefore, be sufficient to meet the needs of a growing ET ecosystem, especially in the areas of nanotechnology and GIS.

¹⁶ Feinson (2003)

¹⁷ Leydesdorff and Zawdie (2010)

¹⁸ Dahlman and Nelson (1995, p 97)

¹⁹ Commission for University Education (CUE) (2021)

Fundamental Activities	Primary Actors	Secondary Actors
Education (post-graduate, short-courses)	Chuka University, DeKUT, Egerton University, JKUAT, Kabianga University, KU, KCAU, Kibabii University, Maasai Mara University, MU, MKU, MMUST, MUST, SEKU, Strathmore, Taita Taveta University, TUK, TUM, UEAB, UoE, UoN.	<p>Governance Framework</p> <p>Ministry of (Agriculture, Education, Health, Industrialisation, ICT), Communication Authority of Kenya, Central Bank of Kenya, Commission for University Education, Competition Authority of Kenya, Kenya Civil Aviation Authority, ICT Authority, National Biosafety Authority, National Commission for Science Technology and Innovation, Office of Data Protection, Kenya Bureau of Standards, Kenya Industrial Property Institute</p> <p>Funding/Resources</p> <p>KENIA, NRF, Government of Kenya, numerous foreign development partners and foundations including Wellcome Trust, VLIR-UOS, Japan International Cooperation, US Army Medical Research Directorate, Bill and Melinda Gates Foundation, USAID, US Centres for Disease Control and Prevention, European Union; large number of foreign and local venture capitalists and investors including Chandaria Capital, Kepple Africa Ventures,</p> <p>Institutions</p> <p>Parliament</p>
Research (basic, developmental and engineering)	Chuka University, DeKUT, Egerton University, IBM Research, ICIPE, ICRAF, IITA, ILRI, IPR, JKUAT, KALRO, Kabianga University, KEFRI, KEMRI, KCAU, KU, Kibabii University, Masai Mara University, MU, MUST, SEKU, Strathmore, Taita Taveta University, TUK, TUM, UEAB, UoE, UoN, Microsoft ADC, IBM Africa	
Implementation (production and commercialisation)	Private Sector (eg.eg. Shamba Records, Utu Technologies, Afya Rekods, Twiga Foods, Farm Economics, numeral IoT, STL Semiconductor), financial institutions, hospitals, government ministries, departments and agencies, SMEs, schools.	
End-Use (customers of the product or process outputs)	Patients, farmers, students, general public.	
Linkages (bringing together complementary knowledge)	Microsoft ADC, ABI Egerton, C4D Lab, Chandaria IBC, DeHUB, IbizAfrica (Strathmore), iHUB, NaiLab, Nakuru Box, Maseno STP, FinTech Association of Kenya, Connected Summit, Natural Products Research for East and Central Africa Network, SBBRA, Africa International Biotechnology and Biomedical Conference, International Service for the Acquisition of Agri-biotech Applications, Open Forum on Agricultural Biotechnology.	

Table 2.1: Key Actors in the ET Ecosystem²⁰

²⁰ ABI Egerton – Agri-Business Incubation and Startup Centre, Egerton University, C4D Lab – University of Nairobi, Chandaria Incubation and Business Centre KU, DeHUB – DeKUT Innovation Hub, DeKUT - Dedan Kimathi University of Technology, ICIPE – International Centre for Insect Physiology and Ecology, ICRAF – International Council for Research in Agroforestry, IITA – International Institute of Tropical Agriculture, ILRI – International Livestock Research Institute, IPR – Institute of Primate Research,

JKUAT – Jomo Kenyatta University of Agriculture and technology, KALRO - Kenya Agricultural and Livestock Research Organisation, KEFRI – Kenya Forests Research Institute, KEMRI - Kenya Medical Research Institute, MMUST – Masinde Muliro University of Science and Technology, MUST – Meru University of Science and Technology, SEKU – South Eastern University of Kenya, TUK - Technical University of Kenya, TUM-Technical University of Mombasa, UEAB – University of East Africa Baraton,

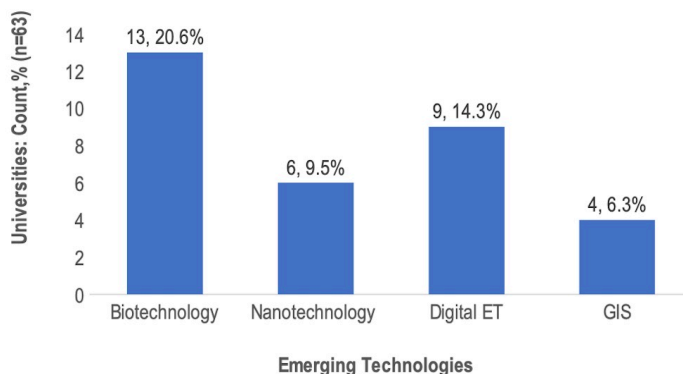


Figure 2.2: Universities offering postgraduate programmes in the identified ETs

The study engaged ten prominent researchers in the ET space with over 148 journal publications. The researchers' views were gathered on their rating of the quality of their post-graduate students on their ability to grasp the concepts, think independently, carry out quality supervised research. This study item served as a proxy/indicator of the students' foundation formed during undergraduate studies. Majority of the researchers, 62.5%, rated the students' ability as acceptable, while only 12.5% rated them as very good as illustrated in Figure 2.3.

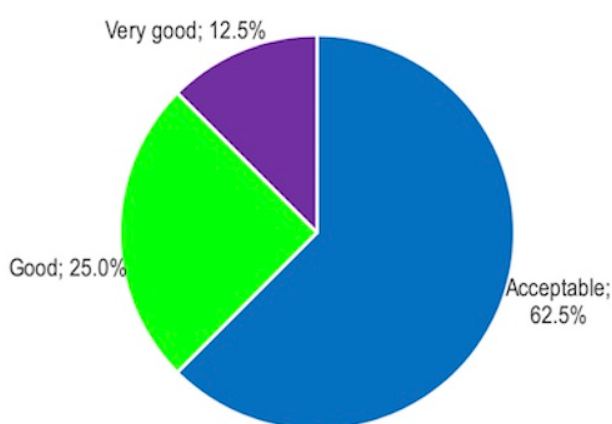


Figure 2.3: Average quality of post-graduate students in ET programmes

2.2.1.2 Primary: Research

Some universities in Kenya are actively engaged in basic and applied research on the identified ETs. Further, in addition to the universities and research institutes, several multinational research and development agencies such as the **Microsoft Africa Development Centre (MADC)** have significantly engaged in various types of research in Kenya. For instance, MADC has been in Nairobi since 2019 working in various areas including software engineering, machine learning, data science, market research and ICT infrastructure. **IBM Research Africa**, located in Kenya and South Africa, is an industrial research agency that seeks to “drive innovation by developing commercially viable solutions to transform lives and spark new business opportunities.”

Among the various outputs of research are publications and patents for technologies with potential for commercialisation. The number of patents applied for and awarded in 2021 was very low at 59 and 12 respectively. Specifically, Kenyans applied for 25 patents on the identified emerging technologies, where 6 were granted. While the level of patenting in the country was generally low, the proportion of patents for ETs was significantly high at 39.3% of the applications and 50% of the awards. Figure 2.4 shows the distribution of the patent applications and awards in Kenya in year 2021.

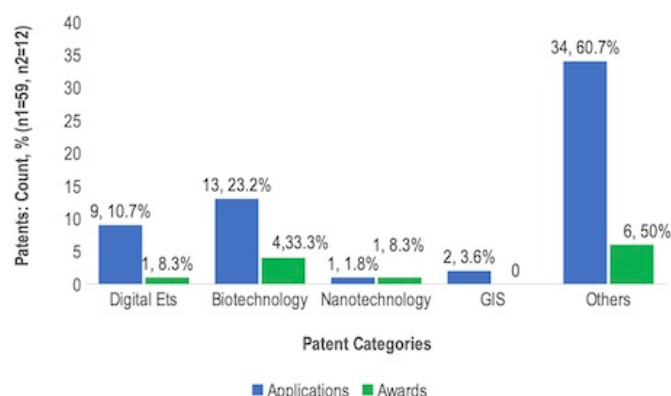


Figure 2.4: Distribution of Patent applications and awards in Kenya in 2021

An assessment of the trend of the number of available postgraduate programmes for each ET and the trend of the number of patents applied for under each ET showed a cointegration of the data series with a positive correlation. Whereas causality may not be declared with certainty, it was observed that more patents are filed by ETs that have higher number of post-graduate programmes. Figure 2.5 shows the relationship between the number of patent applications and the number of programmes under each of the identified ETs.

A key takeaway from the above is that the development of the foundation of an ET's ecosystem as exemplified in the primary actors of education and research hinges on the availability of a critical mass of researchers and their post-graduate students researching in these areas.

The ability to conduct meaningful research, especially in the cutting-edge emerging technologies, requires scientists to have the necessary equipment and facilities. However, the equipment and facilities required for research on the ETs tend to be very expensive. A higher proportion of researchers, 60%, disagreed with the statement, "I have the necessary equipment/tools/facilities to carry out research work in the area of my selected emerging technology", with only 10% agreeing to it. Figure 2.6 shows the extent to which the researchers agreed to the statement, "I have the necessary equipment/tools/facilities to carry out research work in the area of my selected emerging technology".

The above partially explains why most of the commercialised products based on emerging technology research conducted outside the country.

2.2.1.3 Primary: Implementation and end use of ETs

Kenya has had a vibrant production and application record of emerging *digital technologies*, especially in the financial sector as demonstrated in the Global Innovation Index and other internationally recognized rankings. This has been attributed to the vital role played by young innovators and entrepreneurs, as well as industry actors in producing and utilizing these technologies. For example, Kenyan banks and non-banking entities have continued to adopt application of emerging digital technologies such as **IoT, AI, big data/data analytics** and **blockchain** at a higher rate. Leveraging on the well-known and established mobile money transfer service, M-Pesa by Safaricom, several locally developed fintech solutions have emerged and are currently in use in the country. Examples these fintech solutions include Jambo Pay²¹ (an electronic payment platform) and Wapi Pay²² (an Africa-Asia payment platform).

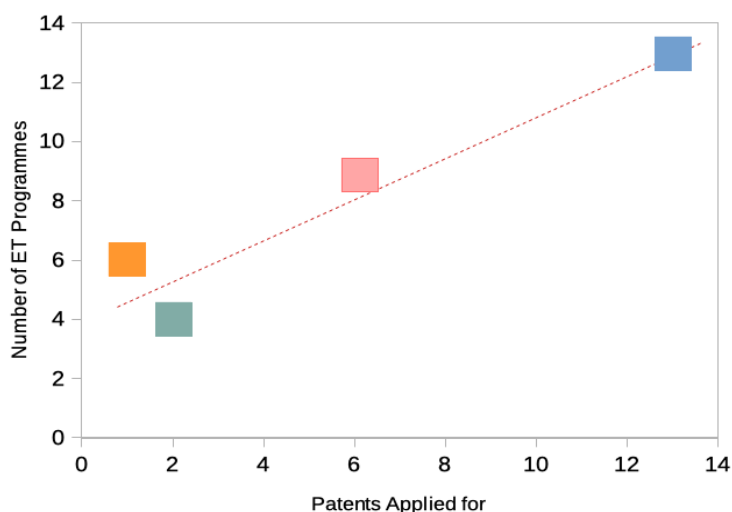


Figure 2.5: Number of patent applications and number of postgraduate programmes under the identified ETs

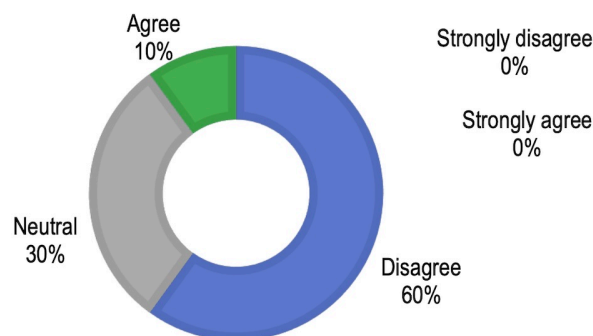


Figure 2.6: Facilities and Equipment for research in the areas of ETs are adequate

²¹ <https://www.jambopay.com/>

²² <https://wapipay.com/>

Other sectors in Kenya, including health, agriculture and manufacturing have also benefited from the digital ETs, which have been produced, adopted and applied in areas such as telemedicine, e-health, health record and information management, farm and soil nutrition management, farmers' online marketplace, product design, energy management and logistics management among others. Examples of solutions in health and agriculture, which have been developed by Kenyans and/or have been adopted for application include Ujuzi kilimo (farm and soil nutrition sensors and data analytics tools)²³, Mkulima Young (an online marketplace for farmers)²⁴, Afyakit (a health analytics platform)²⁵, and Mydawa (an online pharmacy)²⁶.

Big data is a combination of structured, semi-structured and unstructured data collected by organizations that can be mined for information and used in machine learning projects, predictive modeling, and other advanced data analytic applications to create value. It is characterized by great variety, high volume and the need for faster processing making it impossible to process using traditional software. The use and transformative potential of big data and associated data analytics is recognized in various sectors such as agriculture, the public sector administration, energy, health, and manufacturing. However, big data also presents a few areas of concern including ethical data handling and confidentiality. The challenges facing big data and analytics include lack of awareness, representation of whole population and inadequate capacity to process the data among others.

An example of use of big data/data analytics in Kenya can be found in the agricultural sector. The Kenya Agricultural and Livestock Research Organization (KALRO), through the Kenya Climate-Smart Agriculture Project (KCSAP) and the National Agricultural and Rural Inclusive Growth Project has established a big data platform to transform the agriculture and food system in the country. The platform has enabled KALRO to integrate agro-weather data, market data, and farmer data to provide customized geospatial and timely agro-weather and market information to farmers and

policymakers²⁷. In health, the Kenya Health Management Information System (KHMIS) project develops and maintains an integrated National Data Warehouse (NDW) for anonymized patient-level data. The NDW acts as a repository and analytics platform through connection, collation, and aggregation of patient data from all electronic medical records in the country²⁸. Among the uses of the warehouse, the NDW hosts de-identified data to facilitate programmatic monitoring of Health Information System implementations and progress on clinical care and outcomes for HIV infected and exposed persons.

In recognition of the importance of big data and in preparedness to face the associated challenges, the government established the Office of the Data Protection Commissioner (ODPC) in 2019. The mission of this office is to protect personal data through compliance, enforcement, public awareness and institutional capacity development. However, despite this great step, the structures and processes of big data are still developing nationally and not systematically documented. Further, while there are various sector initiatives on use and tapping into the big data, there is weak collaboration among government, research institutions, development agencies and the private sector. Such collaboration is needed to preclude repetitive efforts in data collection, analytics and protection.

In addition to emerging digital technologies, other ETs in the Kenyan landscape are **nanotechnology** and **biotechnology**. Nanotechnology are approaches that manipulate matter at an atomic or molecular scale resulting in materials or devices where at least one-dimension ranges from 1 to 100 nanometers.²⁹ Biotechnology, on the other hand, are techniques that utilise living organisms or substances of these organisms for making or modifying a product for any practical purpose. These techniques include genetic modification (genetic engineering), tissue culture and molecular breeding.³⁰ Applications of nanotechnology and biotechnology can be found in different sectors, primarily in agriculture and health.

²³ <https://www.ujuzikilimo.com/>

²⁴ <https://www.mkulimayoung.com/>

²⁵ <http://www.afyakit.com/>

²⁶ <https://www.mydawa.com/about-us/about-mydawa>

²⁷ <https://olc.worldbank.org/print/content/digital-ag-series-big-data-platform-scaling-data-driven-digital-agriculture-learnings-kenya>

²⁸ <https://kenyahmis.org/documentation/summary-national-data-warehouse/>

²⁹ Gatebe (2012)

³⁰ Karemba et al (2009)

Emerging technologies have diverse benefits to various stakeholders. The Government is one of the key beneficiaries of the emerging digital technologies. Among the digital emerging technology applications adopted by the government include digital services such as the Ardhisasa; a platform³¹ for access to land information and processes undertaken by Government, and e-citizen;³² a service access and payments platform that has significantly improved public service delivery. There are currently over 200 digitized services offered through Huduma Centres countrywide and the online self-service e-citizen platform³³. Digitization of core services such as filing of tax returns, land registries, court procedures and rulings, and public service records is ongoing as the government moves towards its digital transformation journey anchored on various policies and laws. The National Integrated Identity Management System (NIIMS) commenced in 2019 to register all citizens incorporating biometrics to enhance government planning for the provision of public services such as universal health care, education and agricultural extension services³⁴. However, the process was halted in 2020 following a court ruling which faulted the government for failure to put in place an appropriate and comprehensive regulatory framework for protection of personal data collected and safeguarding minorities against discrimination.

Evolution of the digital financial services has been of benefit to citizens, entrepreneurs, SMEs and industries through individual electronic money transfers, retail electronic payment systems, and as a platform for micro-deposits and micro-savings accounts. For instance, the financial sector integration of the mobile platform services with commercial bank services has been useful to the banks, especially in the management of micro-accounts, building deposits, and driving financial inclusion³⁵. In addition, the diaspora community and cross-border businesses have benefitted through improved cross-border/ regional payment systems and international remittance systems.

³¹ <https://ardhisasa.lands.go.ke/home>

³² <https://www.ecitizen.go.ke/>

³³ <https://www.president.go.ke/2021/02/08/kenya-hinging-on-digital-technologies-to-transform-its-economy- president-kenyatta-says/>

³⁴ <https://www.justiceinitiative.org/uploads/477c2588-00eb-4edd-b457-bf0d138fd197/briefing-kenya-niims-03232020.pdf>

³⁵ Ndung'u (2019).

Other sectors, including agriculture, health and education have also been key beneficiaries of ETs. For instance, in the agricultural sector, digital solutions on the management of soil nutrients have been useful to farmers by providing relevant information on type of soils and best crops for productivity. There is also improved farmers' access to the right market through application of digital technology. Further, farmers have benefited from biotechnologically improved high yielding farm crop varieties and productive domestic animal breeds. In the health sector, various stakeholders including hospitals, health centres, clinics and pharmacies have benefited from the emerging digital technologies through effective healthcare data management, online supply of pharmaceuticals, improved healthcare equipment, among others.

2.2.1.4 Primary: Linkages

Linkages with the ET ecosystem are primarily provided by the network of innovation hubs, incubators, accelerators and associations. Their growth has been propelled by the emerging digital technologies. The hubs/centres are actors in the generation of ETs and beneficiaries in providing services for the increasing demand of skills development and support, especially on digital technologies. Several of the key accelerators, incubators and hubs are listed in Table 2.1, with further details provided in Appendix D.

The government is also providing linkages through the development of the **Konza Technopolis**. Konza Technopolis Development Authority (KoTDA) was established to facilitate the development of a world class and sustainable technology hub with a vibrant mix of businesses, workers, residents, and urban amenities. This includes the establishment of a science and technology park that aims at creating a vibrant innovation and technology ecosystem, that is expected to deliver social and economic benefits to Konza Technopolis and its region. This is in line with the government agenda of strengthening the foundation for a knowledge-based economy, enshrined in the Kenya Vision 2030.

Further, several associations have been formed to promote linkages among players in the different ETs. For example, the FinTech Association of Kenya (FINTAK) which is a not-for-profit organization representing leading FinTech companies of all sizes

and serves as a resource and forum for education, information sharing, and networking between companies, policymakers, and the general public;³⁶ and the Society for Biomedical and Biotechnology Research-Africa (SBBRA) who organise the Africa International Biotechnology and Biomedical Conference (bi-annual).³⁷

The study gathered views from ten prominent researchers in the ET space, specifically on whether they are currently engaged in research collaboration with other universities, the industry and or with government entities. The extent of collaboration was high ranging from 70-90% as shown in Figure 2.7, reflecting strong linkages.

2.2.1.5 Secondary: Governance

Globally, the governance ecosystem on ETs has experienced tremendous growth and continues to evolve albeit at a pace slower than innovations in most sectors of the economy. The unprecedented impact of ETs on markets and societies coupled with significant disruptive effects on the traditional factors of production such as labour has shifted regulatory focus to the more profound issue of data governance regarding data privacy, discrimination or the ethical use of data³⁸.

Regulation of ETs remains a complex phenomenon given that there is need to mitigate associated risks while promoting innovation and maximizing benefits for all. Government policies therefore need to balance public interests such as human dignity and identity, trust, nature preservation and climate change, and private sector interests such as business disruption and profits³⁹. Consequently, players have called for new governance frameworks, protocols and policy systems for the new digital era to ensure an all-inclusive system and equitable benefits. The debate on governing the ETs ecosystem has further underscored the importance of holistic regulatory approaches that are human-led and human-centered as well as nature-led and nature-centered⁴⁰.

There is a series of interrelated challenges facing the ETs governance ecosystem particularly resulting from sluggish systems which do not quickly adapt to rapid technological transformation. This is compounded by fragmentation which creates regulatory silos and robustness of outdated rules. The Organization of Economic Cooperation and Development (OECD) 2019 report on *Regulatory Effectiveness in the Era of Digitalization*⁴¹ identifies four challenges that governments are facing in their quest to regulate ETs.

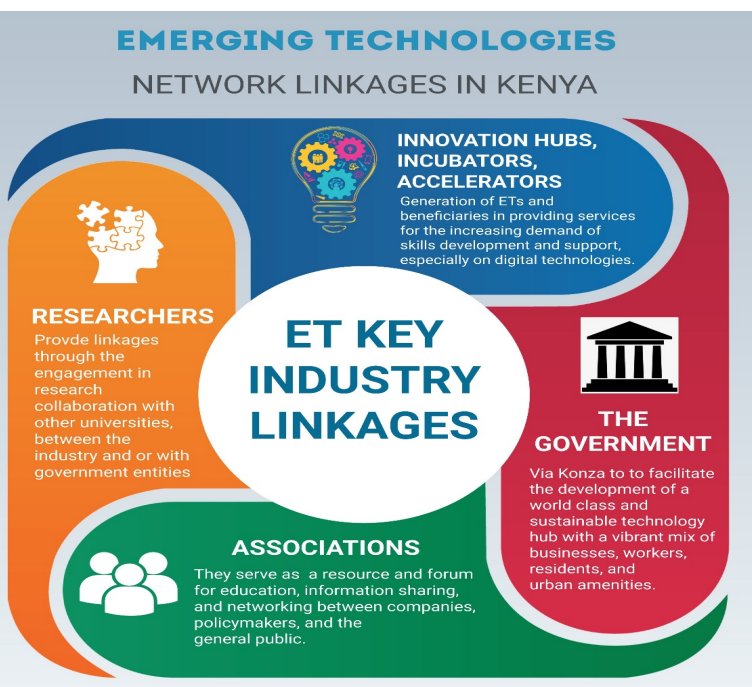


Figure 2.7: ET Network Linkages

³⁶ Kenya's Fintech Association <https://fin-tech.co.ke/>
³⁷ AIBBC, aibbc-society.org
³⁸ OECD (2020).

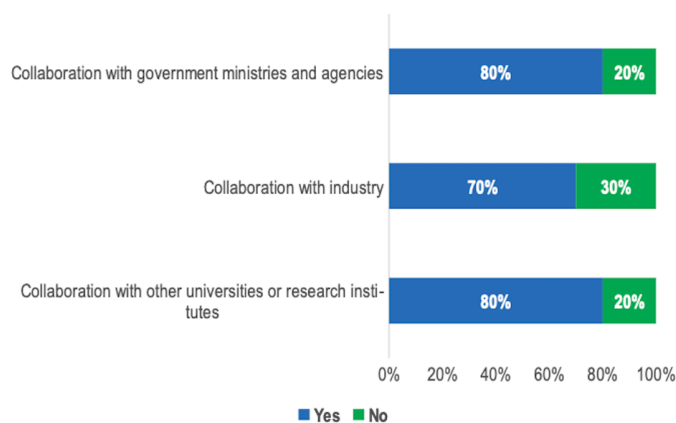


Figure 2.8: Research collaboration among different ET stakeholders

³⁹ ITU (2021)
⁴⁰ Ibid
⁴¹ OECD (2019a)

These are:

- (a) lack of agile regulatory frameworks which can keep pace with the fast-paced technological development;
- (b) reliance on and conformity with traditional designs of “fit-for-purpose” regulatory frameworks often based on market-specific rationales;
- (c) complex regulatory enforcement – with ETs, the notion of liability has become fluid making it difficult to apportion responsibility for damage caused to end users of technology; and
- (d) institutional and transboundary challenges.

In the context of ET, the definition of regulators’ mandates and remits have been challenged by the rapid shifts in the digital space and platforms which blurs categorization into the well-known groups such as producers and consumers. For instance, digital platforms that are increasingly performing functions similar to those of media houses present significant challenges to the traditional approaches of media regulation. The high dependence on data by markets has contributed to unforeseen market failures including implicit transactions, incomplete markets, information asymmetry, copyright infringements, hold-up and locked-in phenomena. Jurisdictional complexities have negatively affected enforcement of tax and data protection laws since the physical presence of businesses ceases to be an important attribute for effective operations. These new realities call for coordination and integration of regulatory practices which are founded on strong multi-stakeholder engagement and multidisciplinary perspectives. This is with a view of building flexible and dynamic regulatory models that are responsive to the ongoing changes with optimal impact.

ETs not only provide new growth opportunities but also create new social and legal challenges. Policies, legislations, regulations and standards are therefore required to govern adoption and application of different ETs, as well as protect the society and environment from anticipated negative impacts. In Kenya, most of the ETs are yet to be comprehensively understood, implying that not all are effectively governed. In some cases, there are concerns that regulations hinder the adoption, application and growth of ETs. For instance, in the case of drone usage, there are restrictive regulations

that have been the cause of outcry from some stakeholders. In biotechnology, specifically the Genetically Modified Organisms (GMOs), the existing policy directives hinder progression on development and adoption of the technology.

Government ministries and regulatory agencies are the main actors in guiding and regulating the adoption and application of the ETs. They engage stakeholders in the development of regulations to ensure inclusion of diverse voices and incorporate the knowledge and experiences of those directly or indirectly affected. The private sector through their associations have stipulated self-regulating rules and mechanisms to support and ensure discipline and effective application of ETs. For example, the Kenya Bankers Association has a self-regulatory framework of standards for member banks to enhance governance and ethical practices in the sector.

2.2.1.6 Phases Defining Kenya’s Governance Frameworks for Emerging Technologies

Kenya’s ETs landscape has grown exponentially thus creating demand for a strong governance framework. The evolution of the ET governance ecosystem has not been in tandem with the rapid technological developments and innovations which have been experienced, particularly over the past two decades. These are developments that have had significant impacts on key industries such as agriculture, banking, e-commerce, finance, health, and logistics. There are several pieces of legislation and policies which have provisions on certain aspects of ETs governance (though not explicitly), and are scattered across production and service sectors leading to incoherence in their application. Regulations for specific sectors are often more stringent as they are defined by the normal mode of operation of the sector rather than its potential for innovation. The financial sector has been the most extreme due to the need for precautionary measures to prevent potential misuse and abuse of new technologies.⁴²

There are multiple regulatory authorities and agencies whose mandates include the regulation of various aspects of ETs in diverse sub-sectors as provided for in the laws that establish them. In the absence of proper intergovernmental agency

⁴² Ministry of Information, Communication and Technology, *Emerging Digital Technologies for Kenya: Exploration and Analysis*, Kenya, July 2019, 9 (1) The Taskforce Report.

coordination mechanisms, there has been several instances of duplication of policies, laws, and regulations leading to poor implementation plans and contradictions. For example, *National ICT Policy Guidelines 2020* (Ministry of ICT) and the *Science, Technology and Innovation Act of 2013* (Ministry of Education) have only slight differences in their provisions. Further, their mandates of implementation are spread across different government agencies without any evidence of a coordination mechanism to synergize efforts and optimal utilization of resources.

The direction and intensity of development of governance instruments on ETs has been influenced by several factors related to changes in the social, economic and political landscape. The change of political regime in 2003, for instance, has been associated with significant policy and legislative formulation to spur economic recovery and growth through, among other things, technological development and adoption of innovations for increased manufacturing, productivity and competitiveness. Other important phases in the country whose implications on ETs governance remain critical are the launch of the Vision 2030 in 2008 and adoption of the new Constitution in 2010. These resulted in intensified efforts geared towards review and development of policies and laws with a view to aligning and harmonizing them with the provisions of these two national documents.

Formation of the *Distributed Ledger and Artificial Intelligence Task Force in 2018* (Ministry of ICT) provided the impetus for the development of a roadmap for ICT-based ETs that will define the evolving 4IR, including AI, Blockchain and IoT. The roadmap defined the way these ETs could promote and enhance government services, including overall public service delivery, job creation through the Ajira Digital Programme, cyber security, trusted single digital identity (*Huduma Namba*), financial inclusion, reduction of transactional fraud, land titling, promotion of democracy, enhancement of the election process, and the precepts of a sharing economy.

The Taskforce report singled out Blockchain and AI technologies as the ETs with the highest disruptive and transformative potential for accelerated realization of the national development goals. The improved efficiency and accountability of Blockchain could considerably benefit government services in

which several emerging markets struggle with inefficient infrastructures and inability to provide fast, accountable and transparent service delivery. It further highlighted the need to invest in a supportive ecosystem and to develop effective regulations to balance citizen protection and private sector innovation.

The National Treasury and Planning, State Department for Planning: Although general in its focus, the *Vision 2030* serves as the reference for the country's ETs governance due to its recognition of Science, Technology and Innovation (STI) as one of the enablers to drive the country's long-term development. Alignment of policies and laws with the Vision remains a major preoccupation of government ministries and agencies as they seek to contribute to the national development goals. The STI Sector Plan for the Third Medium Term Plan 2018-2022 identified emerging issues requiring policy and legislative guideline namely **digital technologies**; space technologies; natural products; industry, oil and natural gas exploitation; **synthetic biology**; **stem cell** and **regenerative medicine**. Other sub-sectors and subject specific areas identified are **biotechnology** and biosciences policies; atomic energy policy and law; **nanotechnology** policy and law; intellectual property policy; and innovation policy. The list of the policies and laws that were required to be enacted within the 5-year period is a clear demonstration of the lacuna which exists and to a large extent, still remains, in the country's governance frameworks for ETs. The development and application of these technologies in the country precedes policy, law and regulation, and where they do exist, they do not match the rapid technological developments.

Ministry of ICT, Innovation and Youth Affairs: *The National ICT Policy (2019)* which is a review of the *National ICT policy of 2006*, is meant to provide a proactive framework that is in tandem with current technological realities and dynamics, and one that will guide the orderly development of the ICT sector. The Policy seeks to create the infrastructural environment that enables the use of always-on, high speed, wireless, internet across the country; facilitate the creation of infrastructure and frameworks that support the growth of data centres, pervasive instrumentation (Internet of Things), machine learning and local manufacturing while fostering a secure innovation ecosystem; increase the overall size of the

digital and traditional economy; grow the contribution of ICT to GDP to 10% by 2030; leverage regional and international cooperation and engagements to ensure that Kenya is able to harness global opportunities; position the country to take advantage of emerging trends such as the shared and gig economy by enhancing education and training institutions; foster an innovation and start-up ecosystem that is able to lead on a global scale; and gain global recognition for innovation, efficiency and quality in public service delivery. The policy's four key areas of focus are mobile first, market, skills and innovation, and public service delivery. The policy is cognizant of the technological trends, including gigabit and petabit wireless, ubiquitous communications, pervasive instrumentation (IoT), big data, deep learning, blockchain and digital currency, the sharing economy, the gig economy, adaptive security architecture, mass personalisation and personalised manufacturing. These emerging trends are among the recommendations of the *2019 Report on Emerging Digital Technologies for Kenya*⁴³.

The recommendations of the 2019 report have contributed to the change of the ETs governance landscape from being cautionary to the creation of a supportive ecosystem to allow multi-sectoral partnerships for the interoperability and scale of Blockchain and AI solutions. This includes a supportive infrastructure (connectivity and electricity), developing the necessary talent, adequate financing mechanisms and an analysis of existing infrastructure and policies that support solutions. Creation of new supportive regulations (such as a Regulatory Sandbox) and removal of regulations that may compromise the development of Blockchain and AI solutions has been proposed to address barriers related to cross border data flow restrictions among other bottle-necks.

To maximize the benefits of digital transformation, the Government in collaboration with various stakeholders has come up with the *Digital Economy Blueprint, 2019*⁴⁴. Recognizing that digital technologies have become the cornerstone of day-to-day activities, the blueprint is based on five pillars namely; digital government, digital business,

infrastructure, innovation- driven entrepreneurship, and digital skills and values.

The Kenya National Digital Masterplan launched in April 2022, whose aim is to provide "quality, accessible, affordable, reliable and secure ICTs in government, with a positioning of Kenya as a globally competitive digital economy."⁴⁵ The Master Plan is built on four pillars: digital infrastructure; digital government service, product and data management; digital skills; and digital innovation, enterprise and digital business. The plan also emphasises through two foundational themes the issues of policy, legal, and regulatory framework; and research and development. The latter theme has been absent from previous Ministry planning documents and underscores the Governments resolve to partner with educational and research institutions. The plan also explicitly recognises emerging digital technologies, primarily AI, IoT, Big Data, and distributed ledgers (block chain).⁴⁶

Ministry of Industrialisation, Trade and Enterprise Development: Through the *National Industrialisation Policy (2012)* the government sought to provide a framework for coordination of the numerous policies, strategies and activities within Kenya's industrialisation process. The policy recognizes the limited linkages between industries, research and training institutions. Low funding and mechanisms for promotion of collaborative research were identified as key impediments to commercialization of research findings. As a result, the policy seeks to develop a framework for commercialization of research findings; formulate mechanisms for collaboration with the private sector in research, technology and development; strengthen capacity for technology certification and adoption; establish a funding mechanism for Research and Development to facilitate innovation, acquisition of strategic and relevant technology for industrial development; and establish an industrial information database. The policy identifies twenty-two priority areas, two of which are biotechnology and nanotechnology-based industries.⁴⁷ Although some success has been registered in biotechnology industries, little has been achieved in developing and growing the number of nanotechnology-based industries.

⁴³ <https://www.ca.go.ke/wp-content/uploads/2019/07/Emerging-Digital-Compiled.pdf>

⁴⁴ <https://www.ict.go.ke/wp-content/uploads/2019/05/Kenya-Digital-Economy-2019.pdf>

⁴⁵ Ministry of ICT, Innovation and Youth Affairs *The Kenya Digital Masterplan 2022-2032*, 2022, p 16.

⁴⁶ Ibid

⁴⁷ Ministry of Industrialisation (2012)

Ministry of Health: Digital technologies used in the health sector are guided by the *Kenya National eHealth Policy 2016-2030*, that seeks to create an enabling environment for the sustainable adoption, implementation, and effective application of eHealth products and services. Key provisions of the policy include equity in distribution of health services and interventions, a participatory approach to the delivery of interventions, efficiency in the application of health technologies, social accountability, and a people-centred approach to health.

Communication Authority of Kenya: The *Kenya Information and Communications (Consumer Protection) Regulations (2010)* seeks to provide for the rights and obligations of the users, along with the safeguards that the telecommunication providers should put in place to protect users' rights. The key provisions include rights and obligations of users to attain clear information on rates, terms and conditions for the available product, personal privacy, to be charged for the products purchased, protection from unfair trade practices, and equal opportunity for access to the same type and quality of service.

Also, the *Kenya Information and Communications Act (Registration of SIM Cards) Regulations 2015* provide a process for the registration of existing and new subscribers of telecommunication services given by telecommunication licensers in Kenya. The regulations provide directions to authorized persons to register a user as a subscriber and the particulars necessary for a user, either citizen, foreigner, or minor, to be registered as a subscriber. They also provide directions for a user who deactivates their SIM card, and the need for security of the subscribers. Both regulations, , are specifically referenced in the *Guidelines for the Use of Internet of Things (IOT) Devices*.

The *National ICT Policy Guidelines 2020* are meant to facilitate formation of the infrastructure and conditions that enable the use of always-on, high-speed, wireless Internet across the country; the formation of infrastructure and frameworks that support the growth of data centres; and pervasive IoTs, machine learning, and local manufacturing. They also seek to foster a secure innovation system, and position the country to embrace emerging ICT trends. As stated in the guidelines, "the Government will concentrate on speeding up the development of new generation mobile, high-speed, secure and

ubiquitous ICT infrastructure, developing a modern technology-enabled industrial system, implementing the national big data strategy and enhancing national cyber-security."⁴⁸ Its key provisions target mobile telecommunication, market, skills, innovation, and public service delivery. Further, it demands all arms of government to build, deploy, operate, and manage regional systems to deliver services, and protect the consumer privacy.

Central Bank of Kenya: Emerging digital technologies have also had a profound impact on the financial services sector. The sector operates under multiple regulations and regulatory institutions which to some extent cause barriers to entry. It has been targeted by private sector players with innovations and emerging digital technologies mostly associated with the mobile phone technology and AI with significant disruptive effects on operations and the regulatory framework. It is important to note that the establishment of MPesa was only possible because Central Bank of Kenya (CBK) granted a regulatory compromise; allowing a telecommunication company to provide banking services.⁴⁹ The CBK Act did not have any express provisions on licensing telecommunication companies to offer financial services⁵⁰. This kind of regulatory compromise or adjustments may be necessary in the wake of leapfrogging technological advancements⁵¹.

The 2014 National Payment System Regulations have provided for the authorization and oversight of payment service providers, designation of payment systems and instruments, and Anti-Money Laundering measures.

With 49 digital credit providers in Kenya, digital lending particularly through mobile telephony has grown exponentially in the past few years⁵². The convenience, ease of access and fast loan disbursement make it an attractive form of borrowing to the users, notwithstanding the high cost of lending. Following public concerns relating to the predatory practices of the previously unregulated Digital Credit Providers (DCP) and especially the high cost of

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<https://www.ict.go.ke/wp-content/uploads/2019/12/NATIONAL-ICT-POLICY-2019.pdf>

⁴⁹ Arunda, Benjamin (2021)

⁵⁰ Ibid

⁵¹ Ibid

⁵² The State of Digital Lending Report, 2021

borrowing, unethical debt collection practices and abuse of personal information, the CBK, vide the Legal Notice No. 46 published the **Digital Credit Providers Regulations, 2022**. The Regulations provide for the licensing, oversight of DCPs, consumer protection and credit information sharing. They also outline the Anti-Money Laundering and Combating the Financing of Terrorism (AML-CFT) obligations of DCPs. Consequently, in accordance with Section 59 (2) of the CBK Act, all DCPs are required to apply for a license within six months of the publication of the Regulations or cease operations.

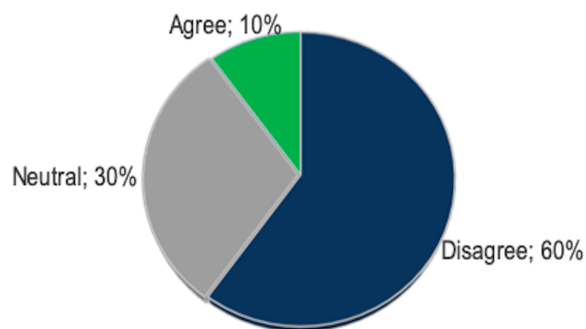
Office of the Data Commissioner: *The Data Protection Act (2019)* established the Office of the Data Protection Commissioner, operationalised in 2020, mandated to *inter alia*, to regulate the processing of personal data; enforce the principles of personal data processing; protect the privacy of individuals and uphold the rights of data subjects through application of relevant remedies. The *Data Protection (General) Regulations 2021* provide procedures for enforcement of the rights of the data subjects along with an elaboration of the duties and obligations of data controllers and processors. Key provisions include enabling the rights of a data subject, for example, being informed on the nature of, the scope of, the reasons for, the required personal data to be processed as well as information on sharing the data with third parties.

Competition Authority of Kenya: Development of the *Consumer Protection Guidelines (2017)* has enhanced consumer welfare in Kenya by providing for consistency, predictability, transparency and accountability in application of consumer protection principles; encouraging the development of a market environment which provides consumers with the greatest product choices while ensuring product safety and quality; and promotion and protection of consumers' health, safety and economic interests.

Kenya Industrial Property Institute (KIPI): The *Industrial Property Regulations (2002)* operationalized the functions of KIPI as provided for in the *Industrial Property Act (2001)*. These include the promotion of inventive and innovative activities as well as the regulation and granting of patents, utility models, technovations and industrial designs.

A summary of key governance actors, policies, legal frameworks, and standards guiding ETs in Kenya is provided in Table 2.2.

Despite having a broad regulatory and governance framework, a survey of researchers working in ETs revealed that only 10% of them perceived the government policies as supportive of research and development, and implementation of ETs (see Figure 2.9). Table 2.3 highlights some of the policies that the researchers would like to see in place to strengthen the current governance framework. Some of the policies are new, whereas some have been in existence, but are currently not effective. Development and implementation of some of these policies provides avenues for collaboration between Kenya, South Africa and the UK. Figure 2.9 shows the extent to which surveyed researchers agreed with the statement; "Current government policies are supportive of research and application of my selected



emerging technology".

Figure 2.9: Government policies are supportive of research and application of the selected ET

2.2.1.7 Secondary: Funding

Production, adoption and application of ETs require a supportive environment and adequate funding. Different actors, including the government, investors, private sector, foundations, philanthropists and development partners contribute in different ways towards facilitation and support of ETs in Kenya. The key facilitators and funders include government ministries and agencies, investors, the private sector, development partners and foundations. Although government ministries and agencies provide some funds in support of R&D, adoption and application of ETs, public institutions majorly contribute to resource

mobilization through provision of guiding policies and supportive infrastructure thus enabling an environment for adoption and application of ETs. The key funders of ETs in Kenya are the private sector players, investors (mostly foreign focusing on ETs of their interest), development partners and foundations. Table 2.4 provides a summary of some of the key funders of ETs in Kenya.

Regulatory Institution/Agency	Policy, Law, Regulation or Guideline	Covers
Ministry of Industrialization, Trade and Enterprise Development	<ul style="list-style-type: none"> National Industrialization Policy, 2012 	<ul style="list-style-type: none"> Seeks to drive commercialization of research output Prioritizes nanotechnology and biotechnology-based industries
Ministry of ICT, Innovation and Youth Affairs	<ul style="list-style-type: none"> The Kenya Information and Communications Act [Rev. 2011] The National ICT Policy, 2019 Digital Economy Blueprint, 2019 National ICT Policy Guidelines 2020 	<ul style="list-style-type: none"> Emerging Digital Technologies
Ministry of Health	<ul style="list-style-type: none"> Kenya National eHealth Policy 2016-2030 Health Information System Policy (2014-2030) 	<ul style="list-style-type: none"> Strategic direction on the use of ICTs in the health sector Guidance on the collection and processing of medical data of patients
Office of the Data Protection Commissioner	<ul style="list-style-type: none"> The Data Protection Act, 2019 	<ul style="list-style-type: none"> Data protection Privacy Regulation on the breach of certain aspects introduced by the IoT
Communications Authority (CA)	<ul style="list-style-type: none"> The Kenya Information and Communications Act (Registration of SIM Cards) Regulations 2015 	<ul style="list-style-type: none"> Data management, Information and Communication, IoT
	<ul style="list-style-type: none"> The Kenya Information and Communications (Consumer Protection) Regulations (2010) 	<ul style="list-style-type: none"> Data Protection - Information and Communication
	<ul style="list-style-type: none"> Guidelines on the use of IoT Devices 	<ul style="list-style-type: none"> IoT
Kenya Civil Aviation Authority (KCAA)	<ul style="list-style-type: none"> The Civil Aviation (Unmanned Aircraft Systems) Regulations, 2020 Unmanned Aircraft Systems – Manual of Implementing Standards, 2020 The Civil Aviation (Regulatory Fees and Charges for Unmanned Aircraft Systems) Regulations, 2020 	<ul style="list-style-type: none"> Regulations and standards of operating drones in Kenya
Central Bank of Kenya (CBK)	<ul style="list-style-type: none"> National Payment System Act, 2011 National Payment System Regulations, 2014 Guideline on Cybersecurity for Payment Service Providers, 2019 Digital Credit Providers Regulations, 2022 	<ul style="list-style-type: none"> Regulation and supervision of payment systems and payment service providers (including Mobile money)
Competition Authority of Kenya (CAK)	<ul style="list-style-type: none"> CAK Consumer Protection Guidelines (2017) 	<ul style="list-style-type: none"> Consumer Data Protection Broad Consumer protection on health, safety and economic interests.
National Biosafety Authority (NBA)	<ul style="list-style-type: none"> The Biosafety Act, 2009 The Biosafety (Environmental Release) Regulations, 2011 Guidelines for determining the regulatory process of Genome Edited Organisms and Products in Kenya, 2022 	<ul style="list-style-type: none"> Biotechnology – Regulation of the transfer, handling and use of genetically modified organisms (GMOs) To provide a technical guidance to applicants and reviewers on the criteria for determining which genome editing techniques and/or derived end products are regulated under the Biosafety Act.

Table 2.2: Key Regulatory Institutions, Policies, Regulations and Standards for ETs in Kenya

Regulatory Institution/Agency	Policy, Law, Regulation or Guideline	Covers
National Commission for Science, Technology and Innovation (NACOSTI), National Research Fund (NRF) and Kenya National Innovation Agency (KENIA)	<ul style="list-style-type: none"> Science, Technology and Innovation Act, 2013 	<ul style="list-style-type: none"> NACOSTI regulates and assures quality in the STI sector, as well as advises the Government in STI matters KENIA develops and manages the National Innovation System NRF facilitates research for the advancement of ST&I through mobilization of resources.

Table 2.2: Key Regulatory Institutions, Policies, Regulations and Standards for ETs in Kenya (Cont ...)

Policy Areas	
<ul style="list-style-type: none"> National Government funding for research Funding and support of research from local governments Policies on and implementation of funding of ETs Policies to motivate researchers' publications, innovations Policies to support institutions with necessary infrastructure (state of the art equipment for science and technology) 	<ul style="list-style-type: none"> Policies to support ownership of patents by the researcher and protection of intellectual property rights Policy on Collaboration between industry and universities Policy on affirmative action on technology adoption Digital Health Strategy Enhanced Data Privacy Policies which promote integration of data and information and access to information on government interventions

Table 2.3: Areas for Policy Development and Strengthening of Research and Application of ETs

Agency/ Institution/ Organization	Role/ Contribution
Investors	
Kepple Africa Ventures	Investing in the development and application of technologies as well as co-creating new industries and fostering growth of start-ups. Examples of tech startups funded in Kenya: <ul style="list-style-type: none"> • <i>Flexpay</i>- pay at your own pace platform on all purchases from various trusted stores/brands; • <i>M-Shule</i>- SMS knowledge-building platform that helps organizations deliver Learning, Evaluation, Activation, and Data tools across East Africa; • <i>Flare</i> - Emergency response technology for both government and private; • <i>Sendy</i> – Tech logistics company.
Chandaria Capital	<ul style="list-style-type: none"> • <i>Lynk</i> - Online platform that partners with Kenyan artisans to showcase and promote their products and services; • <i>SokoWatch</i> - enables informal retailers to order products at any time via SMS or mobile app and receive free same-day delivery to their stores.
Y Combinator	Silicon Valley-based accelerator investing in tech startups. Example of investment in Kenya is: <ul style="list-style-type: none"> • <i>Kidato</i> – Edtech online school.
Village Capital	Supported Kenyan startup is: <ul style="list-style-type: none"> • <i>Ujuzi Kilimo</i> - a farm and soil nutrition sensor and data management.
Energy Access Ventures	Example of Startups supported in Kenya: <ul style="list-style-type: none"> • <i>Mawingu Networks</i> -provides affordable wireless internet in specific hotspots; • <i>PayGo Energy</i> – a distribution service that brings LPG fuel and cooking equipment to homes, installs smart metering systems on gas cylinders that enable customers to pre-pay for cooking gas.
TLcom Capital	Example of supported Kenyan startup is: <ul style="list-style-type: none"> • <i>Twiga Foods</i> - a mobile-based B2B supply platform aggregating retail demand for fresh and packaged food.
Villgro Africa	An incubator and impact investor supporting emerging healthcare businesses. Example of beneficiary: <ul style="list-style-type: none"> • <i>The Pathology Network</i> - a digital referral platform for pathologists in Kenya.
Private Sector and Industry	
Safaricom Spark Fund	Supporting development and growth of high potential mobile tech start-ups, such as: <ul style="list-style-type: none"> • <i>iProcure</i>- an agricultural supply chain platform; • <i>Lynk</i> - a platform that connects households and businesses with informal workers, artisans and tradespeople.
GSMA Ecosystem Accelerator Innovation Fund	Supporting innovative digital solutions with positive socio-economic impact. Example is: <ul style="list-style-type: none"> • <i>Kytabu</i> – Edtech platform providing digital textbooks for rent for

Table 2.4: Key funders of ETs in Kenya

Agency/ Institution/ Organization	Role/ Contribution
	educators and students; <ul style="list-style-type: none"> • <i>Eneza Education</i> - SMS-based educational content for primary and secondary school students.
IBM Research Africa	Supporting development of commercially viable solutions in key areas such as water, agriculture, transportation, healthcare, financial inclusion, education, energy, security and e-government. Example of the projects are: <ul style="list-style-type: none"> • <i>Personalized Learning</i>: Using cognitive systems to help shape the future of education; • <i>Data-driven healthcare</i> - Computational platforms for mining heterogeneous biological and medical data to change ways of prevention, diagnosis, treatment and management of diseases.
FSD Kenya	<ul style="list-style-type: none"> • Supporting development of innovative financial solutions that better address the real-world challenges.

Development Partners

FCDO Gates Foundation GIZ Rockefeller USAID	<ul style="list-style-type: none"> • Nurturing partnership in the development, adoption and application of ETs; • Facilitating technology transfer of ETs; • Financing development, adoption and application of ETs.
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Foundations

AMREF Health Africa Centum Foundation Equity Foundation KCB Foundation MasterCard Foundation Safaricom Foundation	<ul style="list-style-type: none"> • Supporting development, adoption and application of emerging technologies for sustainable development; • Capacity building and mentorship for historically marginalized groups such as young and female entrepreneurs and innovators; • Financing development, adoption and application of emerging technologies.
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Table 2.4: Key funders of ETs in Kenya (Cont ...)

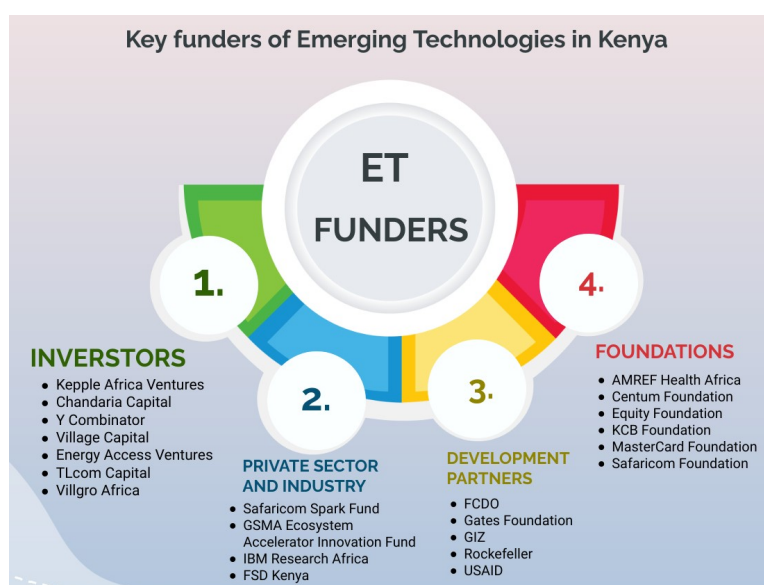


Figure 2.10: Key Funders of ET in Kenya

A survey of researchers working in the areas of the identified ETs revealed that a bulk of research funding in Kenya is foreign. As shown in Figure 2.11, 84% of all projects are funded either by foreign governments or foundations with only 17% funded locally. A key message from this funding profile is that the ETs funded research agenda is primarily driven from outside the country.

2.2.2 State of Maturity

The ETs ecosystem in Kenya was found to be between the **nascent and growth stage of maturity**, based on the analysis of each of the fundamental activities and the roles played by the actors. Looking at each of the fundamental activities, the **education and linkages dimensions was assessed be at the nascent stage of maturity** for the reasons provided in Table 2.5.

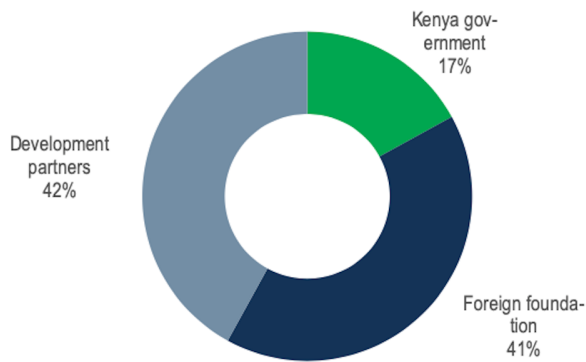


Figure 2.11: Percentage of Funded Projects by Source of Funding






Fundamental Activities	Stages			
	Ideation	Nascent	Growth	
 Education		√		<ul style="list-style-type: none"> • Strong undergraduate degree human resource pipeline with ET related programmes offered by universities ranging from 11.1% for GIS to 52.4% for digital emerging technologies (excluding GIS); • The number of universities offering related post-graduate programmes is still small ranging from 4% for GIS to 13% for biotechnology.
 Research			√	<ul style="list-style-type: none"> • Although the number of total filed and awarded patents in the country remains very low, ETs occupy a significant portion, 39.3% applied for and 50% awarded in 2021; • Large number of publications in journals, dominated by biotechnology; • Large number of pilot projects mainly in agriculture and health; • Local research funding remains very low and is primarily from foreign development partners and foundations; • Strong policies supporting research though most partially or not implemented, e.g. research funding at 2% of GDP and establishment of ET related centres of excellence.
 End use			√	<ul style="list-style-type: none"> • Not uniform across the ETs, strong demand for and better understanding of biotechnology and emerging digital technologies; • Weak demand and end user understanding of the potential for nanotechnology.
 Linkages		√		<ul style="list-style-type: none"> • Not uniform across the ETs; • Strong incubators, accelerator, hub support and infrastructure for emerging digital technologies; • Weaker linkages for biotechnology.
 Implementation			√	<ul style="list-style-type: none"> • Not uniform across the ETs; • Large number of active start-ups or existing businesses who have diversified into emerging digital technologies and biotechnology; • Facilitative governance framework for emerging digital technologies including provisions for data protection; • Growing success in financing for digital emerging technologies and biotechnology.

Table 2.5: Maturity of the different levels in the Emerging Technology Ecosystem

2.3 Biotechnology

Biotechnology can be defined as “any technique that uses living organisms or substances from these organisms to make or modify a product for a practical purpose.”⁵³ There are several biotechnology techniques, the major ones being genetic modification (genetic engineering), molecular breeding (marker-assisted selection) and tissue culture.⁵⁴

Biotechnology has applications across several sectors of the economy with potential for a great impact on the socio-economic development of the country. According to Mtui,⁵⁵ “biotechnology promises to make a significant contribution in enabling the development of better health care, enhanced food security through sustainable agricultural practices, improved supplies of potable water, more efficient industrial development processes, and support for sustainable methods of reforestation and detoxification.” Despite the great potential, current applications of biotechnology in the country have primarily been in agriculture and health.

2.3.1 Key Actors

The primary and secondary actors in the biotechnology ecosystem are presented in Table 2.6.

2.3.1.1 Primary: Education

At the undergraduate level, 36.5% of universities in Kenya offer degree programmes related to Biotechnology, thus providing a robust human resource pipeline for application of existing biotechnologies (see Figure 2.12). At post-graduate level, 20.6% and 14.3% of universities offer biotechnology related Masters and PhD programmes, respectively. These percentages may be adequate to support R&D and develop the required skilled human resource at the post-graduate level.

2.3.1.2 Primary: Research

Agriculture: According to Karembu et al,⁵⁶ “Biotechnology has the potential to significantly increase [agricultural] productivity per unit area of land, reduce the use of pesticides, offer safer and

more nutritious food, and contribute to environmental sustainability.” (4). In Kenya, three biotechnology techniques have been exploited in the agricultural sector namely: tissue culture, molecular breeding, and genetic modification (albeit under controlled trial basis). Most of the agricultural biotechnology R&D, however, is conducted by public research institutions. This differs considerably from the R&D agenda that primarily takes place and is influenced by private sector interests. In Kenya, agricultural biotechnology is still limited primarily to public-funded traditional innovations based on tissue culture and not on genetic modification.⁵⁷

Tissue culture has been widely used for many years now. It can be used to produce, in a laboratory setting, clean, pathogen-free plantlets of vegetative propagated crops. Tissue culture enables mass production of uniform planting materials in short periods of time and providing year-round availability, essential for commercial farming. When carried out properly and with the right crop husbandry, tissue culture plantlets are established faster, have more robust growth, with shorter, more uniform and higher yielding production cycles. Tissue culture has been widely used in Kenya for the production of planting materials for numerous crops including banana, pyrethrum, potato, strawberry, vanilla, oil palm, tea, coffee, potatoes, sweet potatoes, citrus fruits and flowers.

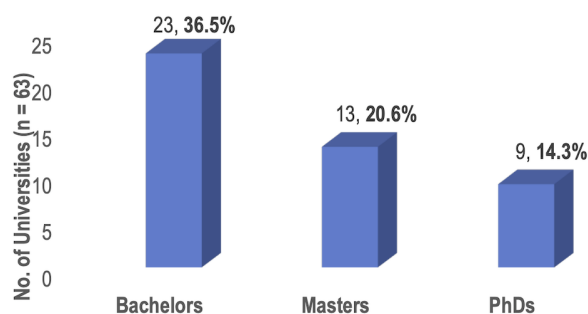


Figure 2.12 Universities offering degree programmes related to Biotechnology

⁵³ FAO (2004 in Karembu et al, 2009).

⁵⁴ Karembu et al, (2009)

⁵⁵ Mtui (2011, p 184)

⁵⁶ Karembu et al (2009 p 4)

⁵⁷ Odame (2014)

Fundamental Activities	Primary Actors	Secondary Actors
Education (post-graduate, short-courses)	Chuka University, Egerton University, JKUAT, Kabianga University, KU, MU, MMUST, MKU, SEKU, TUM, UEAB, UoE, UoN	<p>Governance Framework</p> Ministries (Agriculture, Industrialisation) National Biosafety Authority, Commission for University Education, Kenya Bureau of Standards, NACOSTI, Kenya Bureau of Standards, Kenya Plant Health Inspectorate Services
Research (basic, developmental and engineering)	Chuka University, Egerton University, ICIPE, ICRAF, IITA, ILRI, IPR, JKUAT, KALRO, KEFRI, KEMRI, KU, MU, MMUST, MKU, SEKU, TUM, UEAB, UoE, UoN	
Implementation (production and commercialisation)	Private Sector (eg.), Kenya Veterinary Vaccines Production Institute, KEMRI, JKUAT, Asepsis Limited, Genetic Technologies, Aberdare Technologies, Africa Harvest Biotech Foundation International, Track Green Multi-Purpose Company Limited, Bayer, Corteva Agriscience	
End-Use (customers of the product or process outputs)	Farmers, health professionals, SOBIFAK, veterinarians	
Linkages (bringing together complementary knowledge)	SBBRA, Africa International Biotechnology and Biomedical Conference, International Service for the Acquisition of Agri-biotech Applications, AATF-Open Forum on Agricultural Biotechnology, Natural Products Research for East and Central Africa Network, ABNE- AUDA NEPAD, PBS-IFPRI, KUBICO, Alliance for Science, ABSF	
		<p>Funding/Resources</p> KENIA, NRF, Government of Kenya, numerous foreign development partners and foundations including Wellcome Trust, VLIR-UOS, Japan International Cooperation, US Army Medical Research Directorate, Bill and Melinda Gates Foundation, USAID, US Centres for Disease Control and Prevention, European Union, , USDA, CropLife International, ICGEB, UNEP- CBD

Table 2.6 Actors in the Biotechnology Ecosystem⁵⁸

The techniques have also been used to develop wheat that is tolerant to drought; maize and wheat resistant to aphids; sugarcane resistant to smut; sorghum resistant to striga; and breeding desirable traits in cassava and rice⁵⁹. Given the long period of use, and the adopted definition by Rotolo and Martin⁶⁰ of ETs, tissue culture may no longer be considered an emerging technology.

Molecular breeding (or marker assisted selection) allows the recognition and assessment of beneficial qualities in breeding plant populations. It shortens the process of selecting desired traits, such as increased crop yields, drought tolerance and resistance to pests and diseases, during plant breeding. Use of molecular breeding in Kenya includes understanding the mechanisms of resistance to the maize streak virus; development of maize varieties that are resistant to drought and stem borer pests; disease tolerant coffee arabica varieties, and in the characterisation and conservation of local plant genetic resources.⁶¹

⁵⁸ ICIPE – International Centre for Insect Physiology and Ecology, ICRAF – International Council for Research in Agroforestry, IITA – International Institute of Tropical Agriculture, ILRI – International Livestock Research Institute, IPR – Institute of Primate Research, JKUAT – Jomo Kenyatta University of Agriculture and technology, KALRO - Kenya Agricultural and Livestock Research Organisation, KEFRI – Kenya Forests Research Institute, KEMRI – Kenya Medical Research Institute, MMUST – Masinde Muliro University of Science and Technology, South Eastern Kenya University, SBBRA-The Society for Biomedical and Biotechnology Research-Africa, TUM, University of East Africa Baraton.

⁵⁹ Kabunga et al (2011), Mtui, (2011), Odame (2014)

⁶⁰ Rotolo and Martin (2015)

Genetic modification (or genetic engineering) is⁶² “a process whereby genes are transferred from one living organism to another in order to give them useful and desirable traits such as pest and disease resistance or resilience to harsh environmental conditions.” A Genetically Modified Organism (GMO), therefore, is an organism that has undergone a process of genetic modification to insert a gene (or genes) or modify an existing gene (or genes). GMOs are produced with traits that support increased

⁶¹ Alumiro (2015), Odame (2014).

⁶² Odame (2014)

resistance to pests and diseases (bacteria, fungi, insects, nematodes, viruses), increased tolerance to adverse environmental conditions (drought, extreme temperatures, flooding, heavy metals, soil acidity and alkalinity), increased yield, reduced post-harvest losses, and improved nutritional content.⁶³ Under cautious, controlled and limited trial environments, genetic modification is being used in Kenya to produce crops that are resistant to the cotton bollworm, maize stem borer, cassava mosaic virus, and sweet potato feathery mottle virus, among others.⁶⁴ The country has so far permitted commercial planting of GMO cotton, now running for the second year, and the field trials for cassava have also been approved. The National performance trials on maize were concluded in 2021 and scientists have now applied for commercial release of this variety to farmers.

Whereas crop genetic modification is restricted, the technology can be readily applied to crop pests to reduce their negative impact on yields. Maize, for example, is the primary staple crop in Kenya, and has been negatively impacted by aflatoxin contamination.

Aflatoxins are highly toxic and carcinogenic fungal metabolites. Genetic modification of aflatoxin-producing fungi to produce atoxigenic (non-aflatoxin-producing) strains gives hope in reducing crop contamination by altering the fungal communities so that aflatoxin production becomes rarer. As a result, the mean aflatoxin-producing potential of fungal communities drops, that in turn reduces aflatoxin contamination of crops. This biocontrol technology has been adapted in Kenya (and several other African countries) to reduce aflatoxin in maize and groundnut.

Recent studies have found that the atoxigenic strains were still present in the soils, six years after introduction, demonstrating the long-term influence of the biocontrol application.⁶⁵ Genetic modification has also been more adopted for increasing livestock productivity through development of better vaccines and more accurate diagnostic kits. Examples include the development of recombinant DNA vaccines for Newcastle disease, Rift Valley Fever, and Rinderpest Fever.⁶⁶

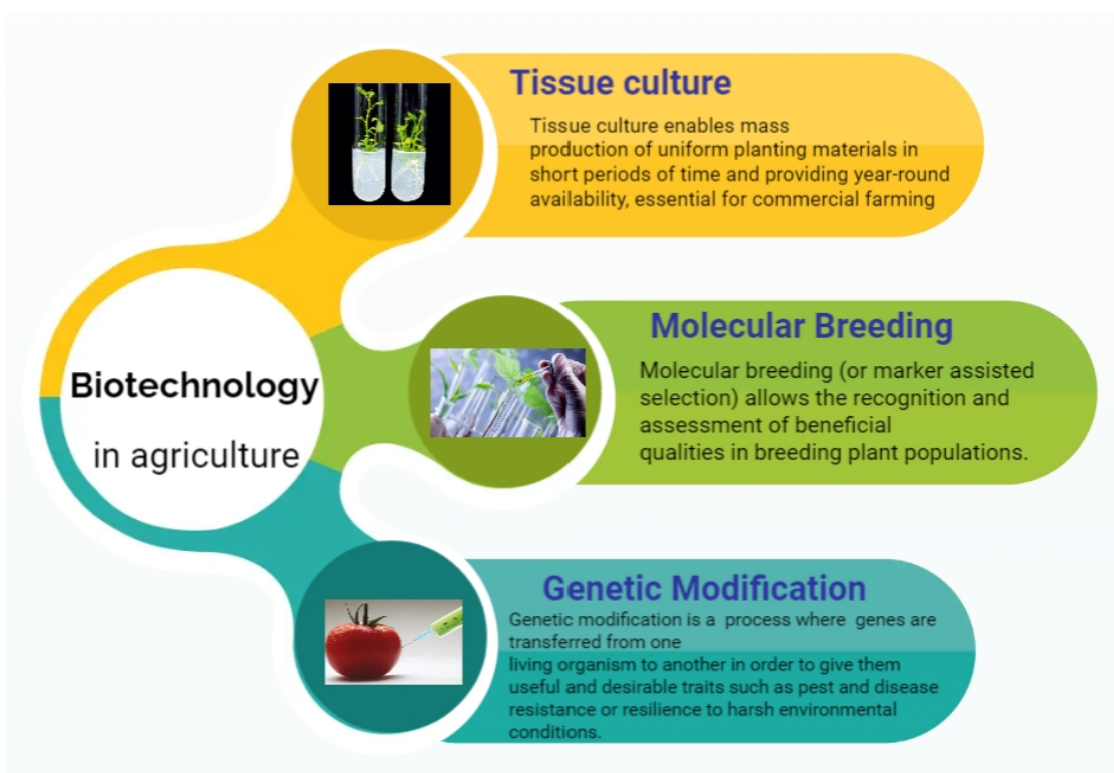


Figure 2.13 Biotechnology techniques in the Kenyan agricultural sector

⁶³ Mtui (2011)
⁶⁴ Odame (2014),

⁶⁵ Islam et al (2021)
⁶⁶ Mtui (2011)

Genome sequencing is a technique to determine the genetic makeup of an organism or cell type to understand how specific diseases form. For example, recent studies in Kenya have looked into the genomes of cassava brown streak viruses that have a negative impact on cassava crop yields in Kenya and Uganda. A vast genetic diversity of the viruses was found and therefore presents challenges in developing molecular diagnostic techniques and control strategies against the viruses.⁶⁷

Health: Genotyping is the biotechnology technique used to establish the differences in genetic make-ups by examining and comparing DNA sequences. The technique has been used in disease vector control in Kenya. For example, Malaria is one of the most prevalent vector-borne diseases in Sub-Saharan Africa with an estimated 602 thousand deaths in 2020, the majority of whom were children below six years and expectant mothers.⁶⁸ Malaria elimination efforts in Kenya have focused on vector control and case management that has resulted in a significant reduction in malaria morbidity and mortality in the country. Shifts in vector behaviour and the development of resistance to insecticides by mosquitoes, coupled with resistance to anti-malarial drugs by Plasmodium parasites that cause the disease would negate these gains. Researchers in Kenya have been able to use genotyping to identify genetic markers associated with insecticide resistance and resting behaviour in mosquitoes in selected sites in Kenya. The use of molecular diagnostic tools as part of insecticide resistance monitoring programmes enables the identification of the genetic markers of insecticide resistance. This is crucial in enhancing the ability to mitigate potential resistance effects.⁶⁹ Similar research has been conducted on human trypanosomiasis with the Tse-Tse fly.⁷⁰ Other researchers have used genotyping to establish the co-morbidity of HIV and Hepatitis B Viruses.⁷¹

Modern biotechnology can also play a leading role in the production of herbal medicines. Medicinal plants have been widely exploited by Kenyan societies to manage various ailments. Traditional approaches of using crude plant extracts, however, is not optimal as

the desired phytochemicals (chemicals produced by plants) may occur at toxic levels with the herbalist or patient unable to determine the degree of toxicity. In addition, the impact on healing may not be optimal as required combinations for the phytochemical may not be attained. Using modern biotechnology techniques in purification and separation of compounds, and metabolic engineering where relative abundance of various phytochemicals can be influenced would result in optimum activity and safety. Metabolic engineering are techniques used to modify cellular metabolite composition to produce new compounds, increase existing compounds, and/or eliminate those that are undesirable. Through genetic engineering, compounds with known important bioactivity related to human health such as antioxidant action, anti-inflammatory and anti-microbial effects can be produced and influenced for continuous supply of rare and expensive secondary metabolites.⁷²

Milugo et al.⁷³ carried out a study to identify the available phytochemicals with known function in human health in quinine tree (*R. caffra*), and to test individual and collective bioactivity of these compounds. Two phytochemicals, alkaloids and saponins, were found to have possible antagonistic effects, where their co-occurrence significantly reduced the antioxidant activity in *R. caffra*. Therefore, alkaloids and saponins should be exclusive to each other in drug formulations. As observed by the research team, "Traditional practitioners administer tissues from quinine tree as crude extracts to their patients ... we show antagonistic relationship among two phytochemicals (alkaloids and saponins), an observation that can only be obvious when the compounds are fractionated and tested separately. Such antagonism ... would affect the efficacy of crude extracts as used in traditional medicine. The data suggested that for pharmaceutical purposes, alkaloids and saponins should be **exclusive** to each other in drug formulations."

2.3.1.3 Primary: Implementation and End Use

Agriculture: Development and commercialisation of livestock vaccines based on biotechnology is undertaken by the Kenya Veterinary Vaccines Product Institute (KEVEVAPI). Established in 1990, the institute has been carrying out research and has

⁶⁷ Kathurima and Ateka (2019)

⁶⁸ World Health Organisation (2021)

⁶⁹ Mwangi-Maini et al (2021)

⁷⁰ Okeyo et al. (2017)

⁷¹ Wandera et al (2022)

⁷² Milugo et al (2013)

⁷³ Milugo et al (2013)

developed commercial vaccines for numerous livestock viruses including Turkey Pox, Rift Valley Fever and Attenuated New Castle Disease. There are also numerous biotechnology-based (excluding those that simply carry out testing) commercial businesses. Examples include *Wanda Agriculture Group*, that among other services, manufactures, imports and markets bio-organic inputs to support current farmers embrace more progressive and sustainable agricultural practices that have proven to increase yields, reduce crop cycles and suppress diseases while improving soil health.⁷⁴

Several tissue culture-based crops have also been successfully introduced among small-scale holder farmers in Kenya through organisations such as the *Asepsis Limited*,⁷⁵ *Genetic Technologies*, *Aberdare Technologies*, *Africa Harvest Biotech Foundation International*,⁷⁶ *Track Green Multi-Purpose Company Limited*, *KALRO* and *JKUAT*. The crops include banana, cassava, strawberry, potatoes, sugarcane, bamboo and aloe vera. Advantages of using tissue culture seedlings include the elimination of risks of pests and diseases and higher yields.

Health: The *Kenya Medical Research Institute (KEMRI)* has been at the forefront in development of commercial biotechnology-based products for human health. This includes the several diagnostic kits, for example, Hepcell Rapid, a chromatographic immune-assay for direct qualitative detection of Hepatitis B; and KEMCOM Rapid, a chromatographic Immuno-assay for direct qualitative detection of HIV 1 and 2.⁷⁷

2.3.1.4 Primary: Linkages

Associations providing linkages within the ecosystem include the *Society for Biomedical and Biotechnology Research-Africa* who organise the Africa International Biotechnology and Biomedical Conference (bi-annual),⁷⁸ among other international organisations that have and continue to hold their conferences in Kenya.

⁷⁴ Wanda Agriculture Group, wandaaggroup.org/our-services

⁷⁵ Asepsis Limited, asepsis-kenya.com

⁷⁶ Bandewar et al (2017)

⁷⁷ KEMRI Biotechnology Programme, <https://www.kemri.go.ke/biotechnology-programme/>

⁷⁸ AIBBC, aibbc-society.org

2.3.1.5 Secondary: Governance

Unlike the ICT-based ETs, biotechnology, specifically as relates to GMOs, has faced a restrictive policy and legislative regime thus limiting growth and application processes. The restrictions emanated from political considerations, and human and environmental safety concerns causing delays and lack of a clear direction on the government's position on its adoption.

National Advisory Committee on Biotechnology Advances and their Applications:

Establishment of a governance framework dates back to 1990 when the government set up the committee. The Committee was charged with (a) setting national priorities based on the Kenya's comparative advantage and its ability to implement traditional biotechnologies in small-scale agriculture; (b) expediting the rapid access to new germ plasm; (c) reducing the cost of agricultural inputs; and (d) accessing affordable and more environmentally sustainable alternatives. The committee's key recommendations presented at the end of the year included the immediate application of tissue culture technique for disease elimination and micro-propagation, the use of Biological Nitrogen Fixation, and the development of disease diagnostic kits. It further noted that the utilisation of modern biotechnology potential remained uncertain due to inadequate regulatory and technical capacity. The recommendations were largely not implemented due to lack of funds. The Dutch Ministry of International Cooperation stepped in and funded the Kenya Agricultural Biotechnology Platform with the mandate to facilitate R&D in agricultural biotechnology for poverty alleviation through, among others, capacity building in biosafety and biotechnology and the establishment of the molecular laboratory at the Kenya Agriculture Research Institute (KARI), today the Kenya Agriculture and Livestock Research Organisation (KALRO).⁷⁹

Biotechnology policy was first introduced through the *National Biotechnology Policy (2006)*. The policy is aligned with the provisions and requirements of the Convention on Biological Diversity and the Cartagena Protocol on Biosafety. Its objective is to ensure that Kenya's biotechnology industry develops in a suitable way to benefit the environment, agriculture, health, industry, and research. The key provisions of the policy include an adequate level of protection in the

⁷⁹ Odame (2014)

field of safe transfer, handling and application of GMOs that might negatively influence human health and environment. Also, the policy directs on the creation of a transparent science-based and predictable process to assess and form decisions on GMOs and related activities.

National Biosafety Authority (NBA): Several subsidiary legislations were enacted to operationalise the Biosafety Act. These include *the Biosafety Environmental Release Regulations (2011)*, *the Biosafety Import, Export and Transit Regulations (2011)*, *the Biosafety Contained Use Regulations (2011)*, and *the Biosafety Labelling Regulations (2012)*. *The Biosafety Environmental Release Regulations (2011)* seek to ensure that potential negative effects of GMOs are resolved to protect human health and the environment when conducting research. Key provisions of the Regulations include applications such as how an individual shall not make an environmental release without a risk assessment conducted by NBA who then issues a written approval.

The Biosafety Import, Export and Transit Regulations (2011) seek to ensure safe movement of GMOs into, across, and out of Kenya while protecting human health and the environment. Key provisions are the distinct procedures on importation, exportation, and transportation of GMOs under containment and confinement. These are applied during research on GMOs while in laboratory, greenhouse growth chamber and confined field trials. On importation, the Regulations stipulate that an individual shall not import GMOs without the NBA's approval, and that the authority shall liaise with the relevant regulatory agency to ascertain that the consignment at the port of entry and exit is consistent with the accompanying documents.

The Biosafety Contained Use Regulations (2011), seek to ensure that the potential adverse effects of GMOs are resolved to safeguard human health and the environment when conducting contained use. The key provisions include the NBA's responsibility in ensuring appropriate measures are undertaken to avoid negative effects on human health and the environment which might arise from the contained application of GMOs; and the NBA performance of risk assessments with the relevant authority to determine the containment level of the contained use

premises in accordance with the provisions of the regulations.

Finally, the *Biosafety Labelling Regulations (2012)* seek to ensure that consumers are made aware that food, feed or a product is genetically modified so that they can make informed choices, and to facilitate the traceability of GMO products to assist in the implementation of appropriate risk management measures where necessary. The key provisions include the labelling requirements of products consisting of or containing GMOs, food or feed produced from GMOs and placed on the market in accordance with the Act, the labelling and packaging of food, feed, or ingredients containing GMOs or products gained from GMOs to be considered after they have undergone appropriate food safety assessment in accordance with the Act, and that the GMOs shall not be described or labelled in a manner that is false, misleading, or deceptive, or is likely to form an erroneous impression regarding their character in any respect.

Despite a strengthened governance framework for biotechnology (primarily focussed on GMOs), the government continues with a precautionary approach to the regulation of genetic modification (GM) technology for crops. The safety concerns have limited development and application of GM biotechnology in the country with regulations permitting only field trials of GM crops, albeit in a highly cautious manner.

Across the region, Kenya with its East African Community partners developed the *East African Regional Bioeconomy Strategy 2021* with the overall objective of achieving sustainable growth and job creation by making full use of the region's bioresources "to develop products in the n the areas of food and nutrition, health, bio-based industrial products, and bio-energy, while contributing to an improved environment and climate change mitigation."⁸⁰ The strategy recognises that to achieve the promises of modern biotechnology, "countries in the region need to develop an enabling environment, where strategic capacity building, partnerships, business incubation, financing mechanisms and supportive policies are key."⁸¹

⁸⁰ East African Community (2021), p 2.

⁸¹ Ibid

The **Kenya Plant Health Inspectorate Service (KEPHIS)** provides a science-based regulatory service by assuring quality of agricultural inputs and produce to prevent adverse impact on the economy, environment and human health. Broadly, the agency provides services in the areas of phytosanitary, seed certification and plant variety protection and laboratory. The Seed and Plant Varieties Act (2012) and the Guidelines for Conducting National Performance Trails and Distinctiveness, Uniformity and Stability Tests on GMOs in Kenya (2018) provide the legal foundation for KEPHIS' operations which cover import and export of plants, plant products and regulated articles.

2.3.1.6 Secondary: Funding

Although the Government of Kenya is a major funder of biotechnology related research and development of products primarily targeting health and agriculture, the bulk of funding for the sector comes from foreign organisations and development partners. The funding covers a wide array of technologies and applications including vaccine development, tissue culture, marker-assisted selection, and genetic modification. Key among the funders are the Wellcome Trust, VLIR-UOS, Japan International Cooperation, US Army Medical Research Directorate, Bill and Melinda

Gates Foundation, USAID, US Centres for Disease Control and Prevention and the European Union.

Funding from multiple foreign sources with multiple agenda, however, has resulted in fragmentation of activities in the sector. Further, as projects are of limited time-frames, over-reliance on foreign funding raises the question of the sector's financial sustainability.⁸²

2.3.1.7 Institutions

Parliament: The biotechnology legal framework was strengthened through the *Biosafety Act (2009)*. The Act provides for a transparent, science-based, and predictable process for assessing and making decisions on the development, transfer, handling, and use of GMOs and related activities. Its key provisions entail defining the establishment, powers, and functions of NBA, the directions on the approval of an individual conducting any activity involving GMOs, the risk assessment performed by taking into account the available information on any known risk posed by potential exposure to GMOs, and the necessary reviews and appeals conducted by NBA on the decisions formed.

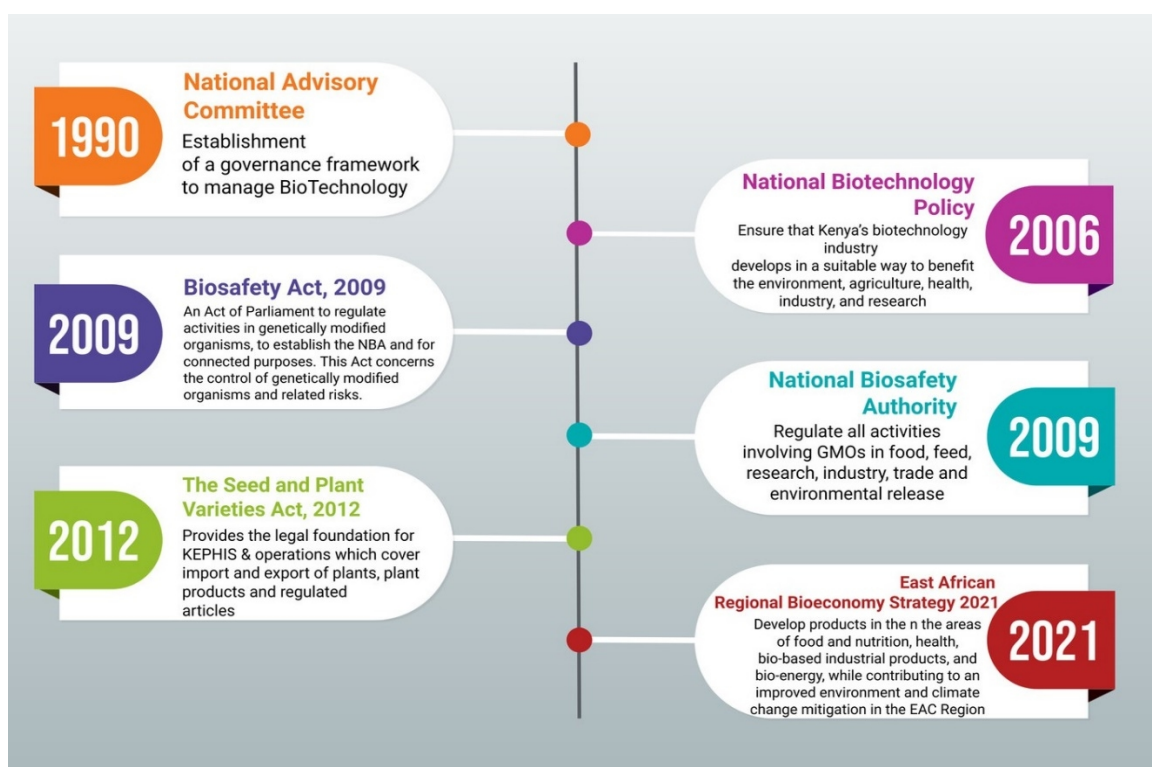







Figure: 2.14 Biotechnology advances in Kenya

⁸² Odame (2014)

2.3.2 State of Maturity of Biotechnology Ecosystem

Fundamental Activities	Stages			
	Ideation	Nascent	Growth	
 Education			✓	<ul style="list-style-type: none"> 36.5% of all universities offer an undergraduate programme providing a foundation for those who may venture into labour markets related to biotechnology or pursue further studies; 20.6% and 14.3% offer related Masters and PhD programmes respectively.
 Research			✓	<ul style="list-style-type: none"> Biotechnology forms the largest proportion of patent applications and awards in 2021 (as a single technology) at 23.2% and 33.3%, respectively; Research on the identified ETs, forms the largest proportion of journal publications; A large number of pilot projects have been carried out mainly in agriculture and health; Local research funding remains very low and is primarily by foreign development partners and foundations; Policies are facilitative on the whole, but restrictive for GMOs that is yet to be fully commercialised.
 End use			✓	<ul style="list-style-type: none"> Strong demand for and use of biotechnology, especially in agriculture and health, though GMO faces regulatory restrictions; Notable efforts to increase awareness on the benefits of biotechnology in mitigating the effects of climate change and assure food security; Tissue culture technology has been embraced across a wide variety of crops.
 Linkages		✓		<ul style="list-style-type: none"> Collaborative engagements between private and public sector players have keenly been pursued to support R&D and related interventions; The Open Forum on Agricultural Biotechnology in Kenya provides a platform for dialogue and raising awareness on agricultural biotechnology.
 Implementation			✓	<ul style="list-style-type: none"> Large number of active businesses are employing biotechnology; In general, there exist facilitative governance framework, though limiting research on and commercialisation of GMOs; There is significant funding (nearly all foreign) in support of biotechnology-based business/organisations focussing on agriculture and health.

Based on the analysis of each of the fundamental activities and the roles played by each of the actors, the overall biotechnology ecosystem is at the growth stage of maturity. The assessment of the maturity state of each of the fundamental activities is shown in Table 2.7

Table 2.7 Maturity of the different levels in the Biotechnology Ecosystem

2.3.3 Potential Areas of Collaboration






Fundamental Activities	Potential Collaboration	Objective
 Education	<ul style="list-style-type: none"> Human resource capacity development and support for infrastructure and facilities; Promotion of knowledge exchange visits and peer learning. 	<ul style="list-style-type: none"> Equipping students with knowledge and skills on the latest developments in the field of biotechnology; Exposing students from UK, Kenya and SA to new sites for experiential learning.
 Research	<ul style="list-style-type: none"> Development of research capacity and resources, especially for Genetic Engineering. 	<ul style="list-style-type: none"> Following a similar development path as done for tissue culture to significantly increase Kenya's research capability in genetic engineering, especially in support of agriculture and health. Key examples include the development of affordable rapid diagnostic tests and strengthening genomics expertise and capacity to detect variants of different viruses.
 End use	<ul style="list-style-type: none"> Supporting existing platforms and establishment of new ones to sustain and intensify public dialogue and raising awareness on biotechnology. 	<ul style="list-style-type: none"> Array public fears on GMO and increase acceptance.
 Linkages	<ul style="list-style-type: none"> Connecting OFAB Kenya and other platforms which convene stakeholders in the biotechnology ecosystem with similar actors in UK; Supporting, strengthening and implementing biotechnology governance framework. 	<ul style="list-style-type: none"> Fostering knowledge exchange and peer learning; Creating an enabling environment for increased multi-stakeholder engagement and generation of evidence for policy development and action.
 Implementation	<ul style="list-style-type: none"> Facilitative role working with industry players enabling the realisation of the full commercial benefits of biotechnology. 	<ul style="list-style-type: none"> Significantly increasing the commercialisation of biotechnology-based products and services in line with Kenya's development aspirations.

Table 2.8: Potential Areas of Collaboration within the Biotechnology Ecosystem

2.4 Nanotechnology

Nanotechnology can be defined as “the study of manipulating matter on atomic and molecular scales [and] involves developing materials or devices possessing at least one dimension sized from 1 to 100 nanometers.”⁸³ These nanomaterials are providing new opportunities across many sectors due to their unique properties. They can be classified into three main categories: organic, inorganic (magnetic and noble metals), and semiconductor nanoparticles (for example titanium oxide and zinc oxide).⁸⁴

Globally, this ET has drawn significant investor and government attention and is referred to as the basis of the 4IR. There are expectations that nanotechnology shall play a significant role in alleviating poverty and promoting sustainable development. This technology is interdisciplinary and has applications that include physics, chemistry, and biology as well as electronics and engineering.

Example practical applications include boosting agricultural productivity, enhancing efficiency of solar panels and cells, enabling provision of safe and clean drinking water, and facilitating targeted drug delivery for improved health.⁸⁵

Limited capital and lack of the technical know-how required to accumulate and exploit nanotechnology, has resulted in countries in the North outpacing those in the South. In sub-Saharan Africa, including Kenya, the required financial and qualified human resources are lacking. Further, “the dynamics of Intellectual Property Rights (IPR), particularly, patents are a formidable barrier in the transformation of expectations of nanotechnology into practical benefits for human development ... there is a risk that nanotechnology may follow the trajectory of patented HIV/AIDS drugs that were not accessible to the poor when they were introduced until countries like South Africa evoked the clause on compulsory licensing, and Zimbabwe declared the pandemic a national emergency to get the drugs at an affordable rate.”⁸⁶ This makes the case for locally developed intellectual property.

⁸³ Gatebe (2012, p 1)

⁸⁴ Kosgei (2021)

⁸⁵ Saidi and Sigauke (2014)

⁸⁶ Maclurcan in Saidi and Sigauke (2014)

2.4.1 Key Actors

The primary and secondary actors in the nanotechnology ecosystem are presented in Table 2.9.

2.4.1.1 Primary: Education

At the undergraduate level, 20.6% of universities in Kenya offer a degree related to nanotechnology, primarily under mechanical engineering programmes (see Figure 2.15). At post-graduate level, there is a drastic drop to 6.3% offering a nanotechnology related Masters or PhD programme. There were no post-graduate programmes specifically on nanotechnology, despite such programmes being common across the globe. Kenya’s Vision 2030 and subsequent Medium-Term Plans have stated that the government shall establish the Kenya Institute of Nanotechnology as a multidisciplinary institution focussed on specialised training on nanoscale science and technology. The institute, however, is yet to be established.

2.4.1.2: Primary: Research

Research in Kenya based on nanotechnology has primarily found applications in the Health, and Water and Sanitation sectors. Research with more general applicability was carried out by Jaramogi Oginga Odinga University of Science and Technology (JOOUST) who patented a novel process that enhances the red light luminescence from layered nanocomposite double hydroxide functional materials. The materials can be applied in different processes that require red light including luminescence such as green houses, paint and photo-voltaic cells.⁸⁷

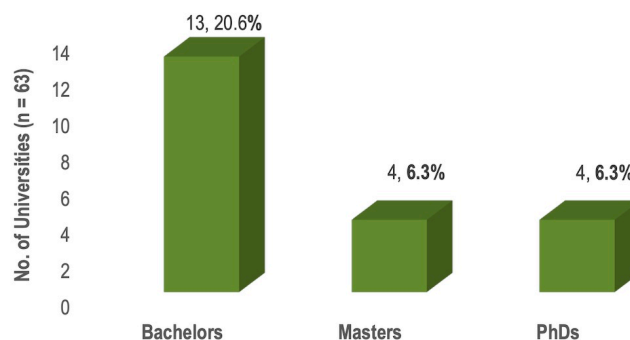
Water and Sanitation: Excess exposure to fluoride of drinking water or food leads to fluorosis that results in dental mottling (less severe cases) to severe skeletal fluorosis causing paralysis of the lower limbs. Millions of people in Kenya are at risk of dental discolouration and serious bone defects due to consumption of high levels of fluoride in drinking water, that is primarily sourced from underground sources. An estimate of 19 million Kenyans suffer from fluorosis.⁸⁸ However, several processes have and continue to be developed and tested using nanotechnologies for ground water purification. Key

⁸⁷ Lugasi (2021)

⁸⁸ Ndambiri and Rotich (2018)

among them are HIX nano materials impregnated with iron (used for the high efficiency absorption of arsenic from water) and with Zirconium (used for high efficiency absorption of arsenic and fluoride). Successful field tests have been carried out in Nakuru showing higher efficiency than current approaches and the possibility of production using locally available materials.⁸⁹ The research on the processes, however, were carried out in the United States and only the field testing was done in Kenya and other countries.

Health: Nanotechnologies have the potential to develop drug delivery mechanisms for diseases including tuberculosis and malaria.⁹⁰ A wide range of nanoscale systems can serve as possible delivery systems including liposomes, micelles, emulsions, nanoparticles, and dendrimers. Nano formulation of drugs has been shown to potentially address pharmaceutical issues including extending the half-life, adding to their performance and acceptability by increasing efficacy or improving safety and patient



compliance. Little work, however, has been done on diseases prevalent in developing countries.

Figure 2.15: Universities offering degree programmes related to Nanotechnology

Fundamental Activities	Primary Actors	Secondary Actors
Education (post-graduate, short-courses)	DeKUT, JKUAT, KU, MMUST, TUK, UoE, UoN	<p>Governance Framework</p> <p>Commission for University Education;</p> <p>No specific governance framework was identified.</p> <p>Funding/Resources</p> <p>KENIA, NRF</p>
Research (basic, developmental and engineering)	DeKUT, Egerton University, IPR, JOOUST, JKUAT, KEMRI, KU, MMUST, Maasai Mara, TUK, UoE, UoN, USIU-Africa, Multimedia University of Kenya	
Implementation (production and commercialisation)	STL Semiconductor	
End-Use (customers of the product or process outputs)	Medical and Healthcare facilities, Cancer patients, Manufacturing such as paint and coating industry, Water purification, general public	
Linkages (bringing together complementary knowledge)	University-Industry (Specifically, DeKUT and STL Semiconductor)	

Table 2.9: Actors in the Nanotechnology Ecosystem⁹¹

⁸⁹ German (2017)

⁹⁰ Beumer (2015)

⁹¹ DeKUT - Dedan Kimathi University of Technology, IPR – Institute of Primate Research, JOOUST – Jaramogi Oginga Odinga University of Science and Technology, JKUAT – Jomo Kenyatta University of Agriculture and Technology, KEMRI - Kenya Medical Research Institute, MMUST – Masinde Muliro University of Science and Technology, TUK - Technical University of Kenya

Researchers from Maasai Mara University and other institutions have been able to formulate nano-scale anti-malarial drugs that were found to have desired nanoparticle characteristics and enhanced efficacy against malaria.⁹² Nanotechnology also offers the potential for improvement in approaches to diagnosis of parasitic diseases such as Bilharzia, and deliver new tools and capabilities to improve the sensitivity. The use of metal nano-particles, for example, has shown significant potential in the development of versatile, highly-sensitive point-of-care diagnostic devices. Gold nanoparticles (AuNPs) have found broad application in biomedical diagnostic assays and imaging due to desired properties that include bio-compatibility, high stability, and ease of characterisation. In 2018, a team of Kenya researchers from Kenyatta University, United States International University-Africa and Multimedia University of Kenya, used nanotechnology to develop a sensitive nano-biosensor for detection of bilharzia that is common in rice-growing regions including Mwea, the Coast and Nyanza⁹³. The bio-sensors, which can be distributed as kits to bilharzia endemic areas can facilitate early diagnosis and treatment. The team further developed and validated the chemistry of their nano biosensor that was tested using stool samples demonstrating the potential of the strips to be used for point-of-care devices to detect bilharzia antigen from stool samples.⁹⁴

Silver nanoparticles (AgNPs) have significant antibacterial properties resulting in their wide use in the medical applications. Examples of these applications include wound dressing agents, food packaging materials, coating of medical devices and anti-septics in health care delivery among others. Further, AgNPs possess anticancer properties associated with their molecular anti-angiogenic and anti-proliferation properties. Conventional approaches to AgNPs synthesis include chemical, photochemical, and physical methods that are all expensive and environmentally unfriendly. Eco-friendly plant-based synthesis provides an alternative cost-effective approach. A team of Kenyan researchers from Egerton University, KEMRI, TUK and DeKUT in 2021, were able for the first time globally, to synthesise and confirm the antibacterial properties of AgNPs using pyrethrum (*C.*

Cinerariaefolium), a process much cheaper and with less impact on the environment.⁹⁵ Further, researchers at Jomo Kenyatta University of Agriculture and Technology (JKUAT) in 2021, filed a patent on a nano-formulated product composition from the *neem* bark extract and AgNPs that they were able to demonstrate had in-vitro anti-proliferative and in-vivo anti-tumor activities.⁹⁶

Agriculture: Nanotechnologies have been used in R&D of different fungicides. For example, a green synthesis process from Silver Nitrate solution to prepare AgNPs from which fungicides were fabricated, had inhibitive properties against *S. Scelerotiorum* that causes *Sclerotinia* stem rot in a wide range of broad-leafed plants, for example soya bean.⁹⁷

Nanotechnologies have also been used to reduce post-harvest losses in fruits. Bananas, for example, are highly commercialised with farmers in Kenya selling about 86% of their harvest. The main growing regions are found in Central and Eastern Kenya. The industry suffers from high post-harvest losses estimated at 40%. This is mainly attributed to poor post-harvest handling, especially due to the high perishability of ripe bananas with a 3-4 days shelf life. An organic nanotechnology formulation called Hexanol has been shown, through trials carried out in 2014-2018, to increase the shelf life of bananas, mangoes and pawpaws by up to 9 days while improving their quality in terms of firmness and colour uniformity during ripening. In Kenya, Hexanol-based formulations (either as a spray or dip) are only available experimentally, although the technology is commercially available in Canada and India.⁹⁸

2.4.1.3: Primary: Implementation and Use

There are very few actual implementations and use of commercial locally developed nanotechnology products. As was presented in the previous section, most work has been restricted to the research and pilot stage, with the bulk of the research being carried out abroad and piloted in Kenya (among other developing countries).

⁹² Omwoyo et al (2016)
<https://doi.org/10.1016/j.nano.2015.11.017>

⁹³ Odundo et al (2018)

⁹⁴ Odundo et al (2018)

⁹⁵ Kosgei et al (2021)

⁹⁶ Kirira, Maina and Mwitari (2021)

⁹⁷ Mwangi (2013)

⁹⁸ Kahwai et al (2021)

The exception is the STL Semiconductor and BG Ndegwa Center for Nano Science and Technology, opened in 2021 at the Dedan Kimathi University of Technology (DeKUT) Science Park. The material sciences facility carries out R&D and manufacturing targeting semi-conductor, agri-technology, biotechnology and energy areas.⁹⁹

2.4.1.4 Primary: Linkages

No current linkage structures, organisations, or associations could be identified focussing on nanotechnology.

2.4.1.5 Secondary: Governance

National Commission for Science Technology and Innovation (NACOSTI): Nanotechnology has had recurring expectations of providing solutions to development problems and to contribute to global development. The government first expressed itself on nanotechnology in 2009 when the Kenya National Council of Science and Technology (NCST) (now NACOSTI) established an *ad hoc* committee on nanotechnology, drawing its members from several research institutions. The committee developed a strategy document making the case to pursue nanotechnology for development.¹⁰⁰

The Committee Chair later from the results of a later study in 2011, noted that Kenya's "efforts should be focused on how nanotechnology can improve

efficiency in manufacturing, energy resources and utilization, reduce environmental impacts of industry and transportation, enhance healthcare, produce better pharmaceuticals, improve agriculture and food production, and expand the capabilities of information technologies"¹⁰¹. In the 2009 report, the Committee noted that the then status of nanotechnology in the country was plagued by minimal understanding, under-developed research infrastructure, few skilled researchers, and lack of standards for nanotechnology products.¹⁰² Despite inclusion of nanotechnology in the *STI Policy (2009)* and the *Kenya National Industrialisation Policy Framework (2010)*, very little had been done to implement these plans by 2015.¹⁰³

Unlike in South Africa where the South Africa Nanotechnology Initiative (SANi) was developed in 2002, in Kenya, any governance framework for the development of this ET is yet to be developed. SANi included academia, research institutions, the private sector and research councils. The South African Department of Science and Technology published the *National Nanotechnology Strategy* in 2005. Through the strategy, nanotechnology was incorporated as a key component of the country's overall development policy.¹⁰⁴

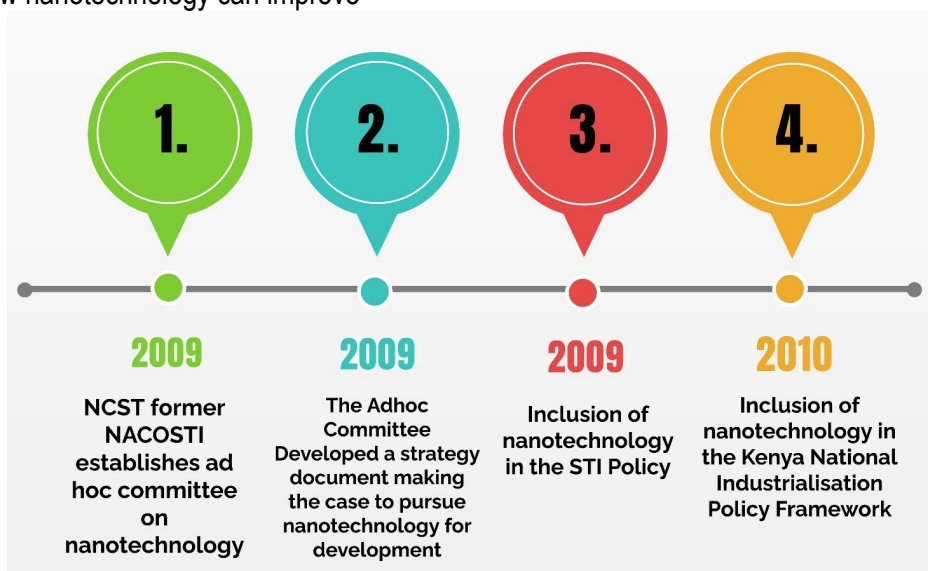


Figure: 2.16 Nanotechnology development in Kenya

⁹⁹ STL Semiconductor, <https://stlsemiconductor.com/>

¹⁰⁰ Beumer (2015).

¹⁰¹ Padh, Aduda and de Alwis. (2011)

¹⁰² Aduda et al (2009) *Ad hoc Committee Report*, p 8 in Beumer (2015)

¹⁰³ Beumer (2015)

¹⁰⁴ Saidi and Sigauke (2014)

2.4.1.6 Secondary: Funding

Minimal funding activities for research or business development related to nanotechnology could be identified.

2.4.1.7 Legislations and Institutions

No relevant legislations or institutions could be identified related to nanotechnology.

2.4.2 State of Maturity of Nanotechnology Ecosystem

The nanotechnology ecosystem was assessed to be at the **ideation stage of maturity**, based on the analysis of each of the fundamental activities and the roles played by each of the actors (see Table 2.10).






Fundamental Activities	Stages			
	Ideation	Nascent	Growth	
 Education	√			<ul style="list-style-type: none"> • 20.6% of all universities offer an undergraduate programme providing a foundation for those who may go into the workforce related to nanotechnology or pursue further studies; • Only 6.3% offer related Masters or PhD programmes.
 Research	√			<ul style="list-style-type: none"> • As a fraction of total patents applied for and granted in 2021, nanotechnology formed a tiny fraction at 1.8% and 8.3%, respectively; • Journal publications based on locally based research were very few; • In 2021, Only 47 nanotechnology-related articles indexed in Web of Science (WoS) from Kenya, which was 1.12% of country's total articles indexed in WoS¹⁰³.
 End use	√			<ul style="list-style-type: none"> • There is still limited understanding of the potential uses of nanotechnology; • Manufacturing sector like paints and coating industry are aware of innovations in nanotechnology, which have globally led to products that can exhibit UV durability, anti-microbial or self-cleaning properties.¹⁰⁴
 Linkages	√			<ul style="list-style-type: none"> • Identified only DeKUT and Semiconductor Technologies Limited partnership that is proposed for setting the pace for local electronic chip manufacturing.
 Implementation	√			<ul style="list-style-type: none"> • Limited commercialisation of products based on locally developed or foreign adapted R&D nanotechnology products; • No governance frameworks in support of nanotechnology-based products were identified.

Table 2.10: Maturity of the different levels in the Nanotechnology Ecosystem

2.4.3 Potential Areas of Collaboration






Fundamental Activities	Potential Collaboration	Objective
 <p>Education</p>	<ul style="list-style-type: none"> • Development of postgraduate programmes in nanotechnology with SA and UK universities offering similar programmes; • Collaborate in Industry-specific trainings on nanoscience and nanotechnology focused on application and relevance in manufacture of devices; • Partner in university curricular reform, faculty training and exchange, and design labs for nanotechnology and nanoscience. 	<ul style="list-style-type: none"> • Develop talent and research capability in nanotechnologies. There are currently no postgraduate programmes specifically on nanotechnologies in the country; • Capacity building; • Skills development.
 <p>Research</p>	<ul style="list-style-type: none"> • Joint long-term research programmes in nanoscience and nanotechnology for application in sectors, such as health on nano-biosensors for diagnostics; • Collaborate in establishment of equipped laboratory necessary for characterising nanoparticles. 	<ul style="list-style-type: none"> • Capacity building; • Co-creation/ co-development.
 <p>End use</p>	<ul style="list-style-type: none"> • Collaborate in localized Nanotechnology innovation and accelerator programs. 	<ul style="list-style-type: none"> • Technology development; • Technology transfer; • Business partnerships.
 <p>Linkages</p>	<ul style="list-style-type: none"> • Kenya-UK industry forum focusing on the nanotechnology products. 	<ul style="list-style-type: none"> • Technology transfer; • Business partnerships.
 <p>Implementation</p>	<ul style="list-style-type: none"> • Development of a Nanotechnologies Strategy and safety regulations, possibly with the Health and Safety Executive; • Policy accelerator program involving key national stakeholders in Nanotechnology. • 	<ul style="list-style-type: none"> • To develop a strategy for the safe exploitation of nanotechnologies to realise their great potential. Further, based on the identified risks develop an occupational regulatory framework; • Support formulation of a guiding and enabling policy.

Table 2.11: Potential Areas of Collaboration within the Nanotechnology Ecosystem

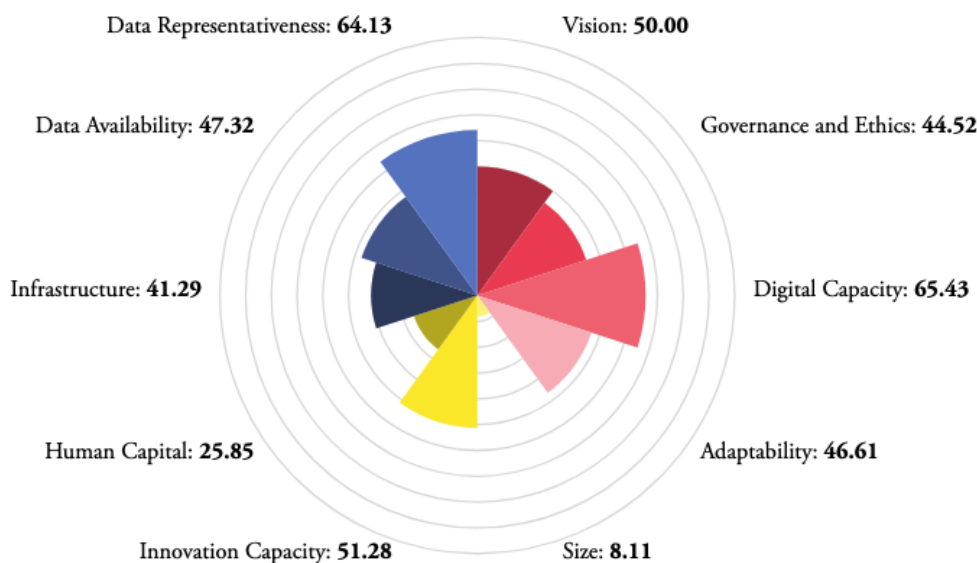
2.5 The Digital Emerging Technologies Ecosystem

Due to their interconnected applications, AI, blockchain, big data/data analytics, GIS and IoT are presented collectively under the banner of digital emerging technologies. *Artificial Intelligence* broadly encompasses systems that incorporate human-level intelligence and at much faster speeds. It includes a rich portfolio of techniques and methods, for example, data mining (including artificial neural networks, Bayesian networks and support vector machines), machine learning, natural language processing, computer vision, and expert systems.¹⁰⁵ Collectively, they provide for enhanced data analytics, better decision-making and improved predictive analysis among others. Although there is no consensus among experts as to what constitutes intelligence, something could be said to act intelligently when: (1) what it does is appropriate for its circumstances and goals; (2) it adapts to changing environments and changing goals; (3) it learns from experience; and (4) it makes appropriate choices given its perceptual and computational limitations.¹⁰⁶

Some of the key sub-fields in AI include expert systems (expert level competence in solving specific problems), natural language processing (computers are able to identify key words and phrases in natural language), and image and signal processing (process large amounts of data from images and signals).¹⁰⁷

The definitions of AI are also broad. For example, the European Commission defines AI as¹⁰⁸ “systems that display intelligent behaviour by analysing their environment and taking actions, with some degree of autonomy, to achieve specific goals”. The Organisation for Economic Co-operation and Development (OECD) defines AI as¹⁰⁹ “a machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations, or decisions influencing real or virtual environments ... [and] are designed to operate with varying levels of autonomy.”

Blockchains are decentralised databases that permanently, without third parties, record user transactions. The transactions are cryptographically chained (so they cannot be altered) and shared with



Source: Oxford Insights, AI Readiness Index 2020, <https://www.oxfordinsights.com/government-ai-readiness-index-2020>

Figure 2.17: Kenya Dimensional Scores, 2020 AI Readiness Index

¹⁰⁵ Mgala (2020)

¹⁰⁶ Poole and Mackworth (2010)

¹⁰⁷ Cossy-Gantner A et al. (2018)

¹⁰⁸ European Commission (2018)

¹⁰⁹ OECD (2019, p 7)

users who are linked. Changes to the transactions can only be made with the consensus of all users.¹¹⁰ From a user perspective, IBM defines blockchain as, “a shared, immutable ledger that facilitates the process of recording transactions and tracking assets in a business network ... An asset can be tangible (e.g. a house, car, cash, land etc.) or intangible (e.g. intellectual property, patents, copyrights, branding etc.) ... Virtually, anything of value can be tracked and traded on a blockchain network, reducing risk and cutting costs for all involved.”¹¹¹ Blockchains therefore, provide for increased efficiency, transparency, and accountability.

Kenya has for the past few years ranked high in Sub-Saharan Africa (4/41 in 2020; 3/41 in 2021¹¹²) and fairly well globally (71/172 in 2020; 78/160 in 2021) on the Government AI Readiness Index.¹¹³ The Index that evaluates how ready a government is to implement AI in the delivery of public services to their citizens is evaluated along ten dimensions as shown by Kenya’s 2020 scores in Figure 2.17.

Big data/data analytics is a combination of structured, semi-structured and unstructured data collected by organizations that can be mined for information and used in machine learning projects, predictive modelling, and other advanced analytic applications to create value. It is characterized by great variety, high volume and the need for faster processing times making it impossible to process using traditional software.

As is the case for AI and Blockchain, there are numerous definitions of *Internet of Things (IoT)*. Oracle, for example, defines IoT as a “network of physical objects—“things”—that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet.” Using combinations of low-cost computing, the Internet cloud, big data, analytics and mobile technologies, physical objects (ranging from every day household appliances to complex industrial applications) can share and collect data with minimal human

intervention. IoT, therefore, represents close cooperation between the physical and the digital world, where the digital systems can record, monitor, and adjust each interaction between physical things.¹¹⁴ Unmanned Aircraft Systems (commonly referred to as drones), for example, represent one of the fastest growing and innovative sectors of the IoT, availing a great commercial and strategic opportunity.

Finally, *GIS* can be defined as “a computer system for capturing, storing, checking, and displaying data related to positions on Earth’s surface. GIS can show many different kinds of data on one map, such as streets, buildings, and vegetation. This enables people to more easily see, analyze, and understand patterns and relationships.”¹¹⁵ The systems that include both hardware and software incorporate many types of data including cartographic, photographic and digital data.

2.5.1 Key Actors

The use of AI, blockchain, big data and IoT in different sectors in Kenya has grown among numerous emerging digital technology start-ups. In addition, several research studies have provided proof-of-concept results, paving way for further development and implementation. The primary and secondary actors and their roles are presented in Table 2.12.

2.5.1.1 Primary: Education

The number of universities offering undergraduate programmes related to the digital ETs in Kenya is robust at 52.4% (see Figure 2.18). The programmes on offer dramatically fall at Masters and further at PhD level where they are only offered by 12.7% and 6.3% of the universities respectively. These exclude GIS that has its own programmes. Whereas this provides an excellent human resource for the development of products and services based on current technologies, the country remains relatively weak in the development of new technologies. For GIS, the proportion of universities offering related undergraduate programmes is 11.1%, with only 6.3% and 3.2% offering the programmes at Masters and

¹¹⁰ Ministry of Information, Communication and Technology (2019)

¹¹¹ IBM, “Blockchain Overview” <https://www.ibm.com/topics/what-is-blockchain>

¹¹² In 2021, Mauritius was ranked first in Africa followed by South Africa.

¹¹³ Oxford Insights and IDRC (2020, 2021)

¹¹⁴ Oracle, *What is IoT?* <https://www.oracle.com/internet-of-things/what-is-iot/>, viewed April 6, 2022.

¹¹⁵ National Geographic Society, www.nationalgeographic.org/encyclopedia/geographic-information-system-gis/

PhD levels respectively. There is, therefore, a very weak human resource pipeline in support of local research and development in GIS.

2.5.1.2 Primary: Research

The recent entrance of multi-national and development partner Research & Development centres has added to the growing category of primary actors. They are tapping into the local pool of expertise to undertake local-oriented R&D while acting as nodes within their global R&D activities. For example, the **Microsoft Africa Development Centre** has been in Nairobi since 2019 working on areas such as software engineering, machine learning, data science, market research and ICT infrastructure.

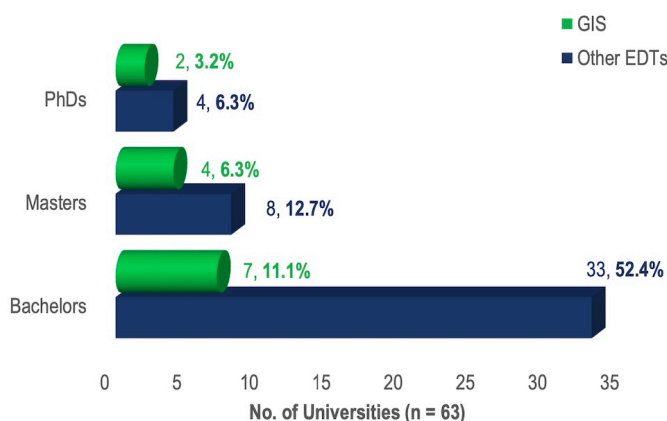


Figure 2.18 Universities offering degree programmes related to GIS and other Emerging Digital Technologies (EDTs)

Fundamental Activities	Primary Actors	Secondary Actors
Education (post-graduate, short-courses)	DeKUT, KCAU, KU, Kibabii University, Masaai Mara University, MKU, MUST, Strathmore University, Taita Taveta University	<p>Governance Framework</p> <p>Ministry of (ICT, Education), ICT Authority; Communication Authority of Kenya, Competition Authority of Kenya, NACOSTI, Kenya Civil Aviation Authority, Office of Data Protection, Central Bank of Kenya, Commission for University Education</p> <p>Funding/Resources</p> <p>KENIA, NRF, large number of foreign and local venture capitalists and investors including Chandaria Capital, Kepple Africa Ventures</p>
Research (basic, developmental and engineering)	IBM Research, KCAU, KU, Kibabii University, Masaai Mara University, MKU, Microsoft ADC, MUST, Strathmore University, Taita Taveta University, TUK, TUM, UoN	
Implementation (production and commercialisation)	Private Sector (eg. Shamba Records, Utu Technologies, Afya Rekods, Twiga Foods, Farm Economics, Pezesha, numerallOT), SMEs, financial institutions, health facilities, schools, government ministries, departments and agencies,	
End-Use (customers of the product or process outputs)	Patients, students, farmers, general public.	
Linkages (bringing together complementary knowledge)	Ihub, Kilifi County AgriBiz Hub, IbizAfrica (Strathmore), NaiLab, C4DLab (UoN), Nakuru Box, Lake Hub, Swahili Box, Microsoft ADC, Chandaria IBC (KU), DeHUB (DeKUT), iHUB, FinTech Association of Kenya, Connected Summit, Computer Society of Kenya, Kenya ICT Action Network	

Table 2.12: Actors in the Emerging Digital Technologies Ecosystem¹¹⁶

¹¹⁶ DeKUT – Dedan Kimathi University of Technology, MUST – Meru University of Science and Technology, TUK- Technical University of Kenya, TUM – Technical University of Mombasa

In March 2022, they moved into a new state-of-the-art facility. Within the Centre, is the Microsoft Garage, a structured freeform workspace where MS employees, community groups, business groups, schools, and interns are availed tools and training to support them in learning skills and launching new products. **IBM Research Africa**, anchored in Kenya and South Africa, is an industrial research facility that seeks to “drive innovation by developing commercially viable solutions to transform lives and spark new business opportunities.” Their digital products, based on AI, blockchain, and data analytics (among others) are supporting businesses in the areas of water, agriculture, transportation, healthcare, financial inclusion, education, energy, security and e-government.

Research output that can be commercialised, as measured by number of patents, remains low (as overall patent protection in the country is low). Recently, a team from JKUAT developed and applied for a patent for a system that is able to optimise contextual cartographic content for location-based navigation systems using a combination of mobile technology, internet service, geospatial data and topology, and satellite positioning components.¹¹⁷

Health: Health informatics is the acquisition, storage, retrieval and use of healthcare information to improve the care of patients during their interactions with the health system. Electronic medical records combined with AI provide opportunities to improve patient care, decision-making and public health informatics.¹¹⁸ For example, an electronic medical records system, *Bora*, has been used in Kenya to improve on maternal and child health and HIV treatment. The pilot study in 2015 found that the system helped to close critical gaps in care.¹¹⁹ IBM Research Africa is developing computational platforms and tools (for example understanding natural language and images, bioinformatics) enabling mining of biological and medical data to transform the prevention, diagnosis, treatment and management of disease, with a current focus on tuberculosis and HIV.¹²⁰

Education: Poor performance in the Kenya Certificate of Primary Education (KCPE) exams often

serves as a strong indicator of those students meeting their career aspirations. AI tools were effectively used to identify students two years prior to the KCPE exam, that need intervention to improve their performance in the exam. Based on student records, the intervention prediction models in the pilot study were relatively accurate in enabling educators to take appropriate measures early enough.¹²¹ IBM Research Africa has been working with RTI International to use AI, cognitive and mobile technologies targeting schools where students are most at risk to fail. The initiative captures data including class size, grades, school resources, among others to propose various interventions. IBM is also exploring AI technology that can support students in Nairobi to personalise their learning experience.¹²²

2.5.1.3 Primary: Implementation and End Use

Agriculture: *Shamba Records*,¹²³ based in Nairobi, provides several digital tools leveraging on AI and Blockchain to help farmers in sub-Saharan Africa increase their yields, become more profitable, track and trace their crops, and exploit new market opportunities. For example, their real-time data collection tool collects farmer’s production data, linking it to aggregation centres and the market. For the entire process, the company automates payments to the farmers, credit scoring, credit issuance, market linkage and agricultural extension services. The company leverages on blockchain technologies in their processes to eliminate ghost farmers and prevent manipulation of farm or harvest records. The technology is also used to implement smart contracts between farmers leasing land from other farmers. In 2019, it was used by more than six thousand farmers in Kenya in the coffee, tea, and dairy sectors.¹²⁴

Hello Tractor, a company that started in Nigeria and now also based in Nairobi, has developed an IoT platform to connect farm equipment owners, dealers and banks with farmers who need those services. The platform simplifies and makes fleet management more profitable. It supports every aspect of a tractor fleet from the operators to the farmer customers by

¹¹⁷ Wasomi et al (2021)

¹¹⁸ Cossy-Gantner A et al. (2018)

¹¹⁹ Haskew et al. (2015a), Haskew et al. (2015b)

¹²⁰ Data Driven Healthcare, <https://research.ibm.com/labs/africa/#projects>

¹²¹ Mgala & Mbogho (2015)

¹²² African Schools are using Cognitive systems to help shape the future of education. <https://research.ibm.com/labs/africa/#projects>

¹²³ Shamba Records, <https://shambarecords>

¹²⁴ Jackson (2019)

enabling the farmer to request affordable tractor services and providing enhanced security to the owners of the tractors through remote asset tracking (using Global Positioning Systems – GPS) and virtual monitoring (fuel management, driver management, fraud reduction).¹²⁵

Financial and Business Services: There are a very large number of fintech businesses leveraging on emerging digital technologies. Examples include; *IBM Research Africa*, based in Nairobi, which teamed up with business-to-business food distribution



Figure 2.19 Use of Blockchain Technology in the Agriculture Sector

¹²⁵ Hello Tractor, <https://hellotractor.com>; Jackson (2019b)

company *Twiga Foods* to use AI, Blockchain and big data to develop credit profile for hundreds of SMEs, who were then able to access non-collateralised microloans to purchase supplies from them. Many of the recipients in the pilot project, would not have qualified for regular bank loans. They often lacked adequate data or tools to analyse the data to make informed decisions for this segment of the market. Isaac Markus, a researcher at IBM explains, “After analysing purchase records from a mobile device, we used machine learning algorithms to predict creditworthiness, in turn giving lenders the confidence they needed to provide microloans to small businesses. Once the credit score is determined, we used a blockchain ... to manage the entire lending process from application to receiving offers to accepting the terms of repayment”¹²⁶

Start-up *Utu Technologies*¹²⁷ is leveraging on AI and Blockchain to provide a trust infrastructure on the internet, replacing current anonymous star ratings, reviews and scores. Their software and platform replaces these approaches with AI-based tools that adapt to users’ preferences and context, allowing businesses to provide personalised recommendations, thereby increasing conversions and sales. They use blockchain to ensure that reviews and ratings cannot be manipulated.

Pezesha leverages on AI to provide a digital lending infrastructure and marketplace that connects small and medium businesses with working capital. Their system supports alternative credit scoring and lending infrastructure as a service.¹²⁸ Similarly *Cherehani Africa* provides credit services by leveraging mobile-based technology to provide credit and distribute personalized financial literacy content to women and adolescent girls who own micro-enterprises.¹²⁹

A community inclusion currency (or vouchers) *sarafu*, developed by *Grassroots Economics* a Kenyan non-profit foundation, leverages on blockchain to empower marginalised communities to take charge of their own livelihoods and economic futures. In 2020, for example, the “currency” was used by over Forty-One Thousand people in 60 villages across Kenya who in 2020 carried out 335,000 transactions equivalent to \$2.5 million, using their mobile phones. Using USSD technology on the phone, users can access the platform even where there is no Internet. Community inclusion currencies enables groups to come together, form their own currencies and build a resilient economic system from the bottom up.¹³⁰

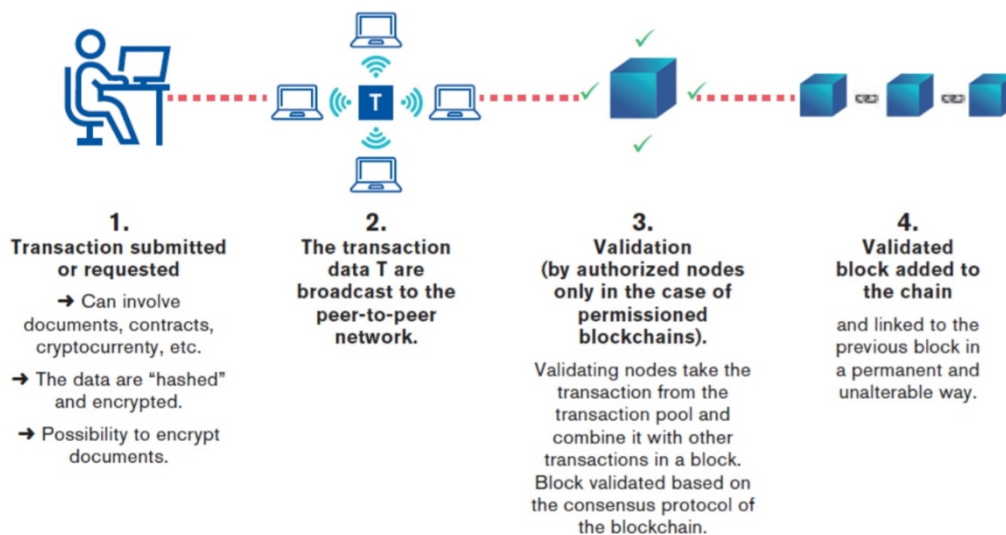


Figure 2.20 Use of Blockchain Technology in the SME Sector

¹²⁶ Jackson (2018)

¹²⁷ Utu, utu.io

¹²⁸ Pezesha website, pezesha.com

¹²⁹ Cherehani Africa, cherehani.org

¹³⁰ Adriano (2021); Grassroots Economics, grassrooteconomics.org

Health: A commercialised AI and Blockchain-based digital platform, *Afya Rekod*, is premised on the notion that the patient should maintain the sovereign right of ownership of their health data. The electronic medical records platform allows health facilities and patients to use the data to make informed decisions resulting in doctors providing better healthcare to the patients. The platform allows doctors to manage a patient's health data in real-time and have access to the patient's data from all health facilities they have visited before. On a broader scale, anonymised data can support disease tracking and mapping of different outbreaks and pandemics.¹³¹

A team of researchers carried out a pilot study in Kinondo to establish whether point-of-care digital microscopy and AI-based assessment of samples (through image and signal processing) can be used to analyse cervical cancer tests results. This is important, noting that although cervical cancer is highly preventable, it remains a common and deadly disease in areas where there are no screening programmes due to a lack of pathologists. Their AI-supported approach was able to detect atypical cervical smears with the same high sensitivity as a visual analysis done by a pathologist.¹³²

The same concept was applied to automatically analyse digital retinal images to detect diabetic retinopathy, which if left untreated can lead to visual impairment or blindness. A pilot study carried out in Nakuru in 2015 found the automated analyses of retinal images had the same accuracy as those done by trained humans.¹³³ Both examples show how AI-based image screening can serve as an effective diagnostic approach where there is lack of human expertise

Cross-Cutting: *numeralIoT* is an electronic design and manufacturing company which has developed products and services that leverage on AI and IoT. They also provide electronic design and manufacturing support to other businesses. Examples of their products include 4G speed governor, vehicle tracking and security devices and cashless payment solutions.¹³⁴

2.5.1.4 Primary: Linkages

Linkages are primarily held by innovation hubs, incubators, accelerators and the relevant associations. A comprehensive list of examples is provided in Appendix D. **iHub** in Nairobi has an Open IoT programme, launched in September 2020 (in partnership with GSMA Africa).

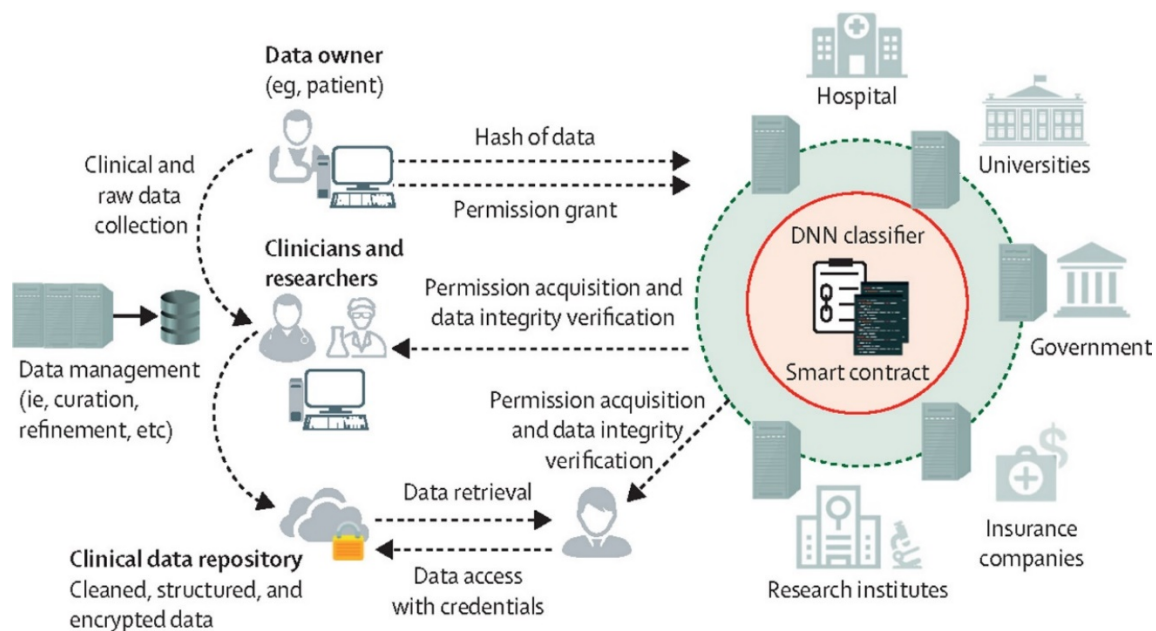


Figure 2.21 Use of Blockchain Technology in the Health Sector

¹³¹ Afya Rekod, afyarekod.com

¹³² Holmstrom et al (2021)

¹³³ Hansen et al. (2015)

¹³⁴ numeralIoT, www.numeraliot.com

The programme is a pan-African IoT community platform, facilitating conversations supporting the growth of the African IoT ecosystem. Based at Strathmore University, **IbizAfrica** is a business incubator that focusses on ICT solutions. They offer mentoring, business training, seed capital, and legal advice. **NaiLab** is an ICT incubator that provides a simplified platform for innovators to be found by venture capitalists and business angels and investors.

Other organisations provide start-ups and businesses with digital emerging technology tools for their applications, products and services. For example, the **bHUB**¹³⁵ supports start-ups integrate emerging digital technologies into their applications and platforms. They also organise various networking events including open and investor forums.

In addition, there are several annual conferences that bring together players in the sector. For example, the Connected Summit has been organised by the ICT Authority and the Ministry of ICT since 2009. It brings together over One Thousand leaders, policy makers, industry champions and executives, financiers, and ICT innovators, and¹³⁶related associations and networks including the Computer Society of Kenya,¹³⁷ and the Kenya ICT Action Network.¹³⁸

2.5.1.5 Secondary: Governance

For emerging digital technologies, the Government is following an approach that takes into account how best to protect citizens, ensure fair markets, and enforce regulations while at the same time enabling the technologies and businesses to thrive. The approach is one of:^{f.139}

- (a) *Adaptive regulation*. Shift from “regulate and forget” to a responsive, interactive approach.
- (b) *Regulatory sandboxes*. Prototype and test new approaches by creating sandboxes and accelerators.
- (c) *Outcome-based regulation*. Focus on results and performance rather than form.

- (d) *Risk-weighted regulation*. Move from one-size-fits-all regulation to a data-driven, segmented approach.
- (e) *Collaborative regulation*. Align regulation nationally and internationally by engaging a broad set of players across the ecosystem.

Communication Authority of Kenya (CA). The *Guidelines on the Use of the Internet of Things (IoT) Devices* seek to promote the use of IoT, machine-to-machine based devices (M2M), and devices with embedded Universal Integrated Circuit Card (UICCs). The guidelines provide for the type of approved devices with embedded UICCs in accordance with Kenya Information and Communication Regulations (2010) and the architecture the devices need to comply with. They also inform the use of Mobile Station International Subscriber Directory Numbers (MSISDNs) and on the activation of IoT and M2M devices and those with eUICC through subscriber registration in accordance with the Kenya Information and Communications Act (2015) and the Kenya Information and Communications Act (Registration of SIM Cards) Regulations (2015).

Kenya Civil Aviation Authority (KCAA): Several regulations developed and overseen by the Authority address the drones sector of IoT. *The Civil Aviation (Unmanned Aircraft Systems) Regulations (2020)* seek to regulate the Unmanned Aircraft Systems. Key provisions include KCAA’s determination of additional requirements and specifications for operation in each category such as the individuals eligible in owning UAS, the transfer of UAS ownership, and the authorization of importing UAS. *The Civil Aviation (Regulatory Fees and Charges for Unmanned Aircraft Systems) Regulations (2020)* seek to provide a new charging structure of owning or operating a UAS. These include the registration fee charges, the categorization of UAS based on the risk posed by their operations to public safety and security, and the purpose of the UAS. Finally, the *Unmanned Aircraft Systems – Manual of Implementing Standards (2020)* provides guidelines for establishment and implementation of a system for registration and identification of UAS. Key provisions define who is eligible to own and fly a UAS, essentially Kenyan citizens aged above 18 years who are licensed by the government. Locally registered companies are eligible to own drones after gaining the license.

¹³⁵ bHUB, thebhub.co.ke

¹³⁶ Connected Summit, connected.go.ke

¹³⁷ Computer Society of Kenya, www.cskonline.org

¹³⁸ Kenya ICT Action Network, www.kictanet

¹³⁹ Ministry of ICT (2019)

Central Bank of Kenya (CBK): In the wake of Blockchain-based cryptocurrencies such as Bitcoin and Ethereum, the banking industry will require robust and up-to-date regulatory provisions to mitigate the associated risks. Adoption of cryptocurrencies pose a threat to the centralization of banking services that allows regulators to play the watchdog role. Further, such currencies may foster money-laundering and financing of terrorism activities.¹⁴⁰ Through the *Banking Circular No. 14 of 2015*, the CBK issued a cautionary statement to financial institutions against dealing in virtual currencies stating that they are unregulated, untraceable and anonymous.

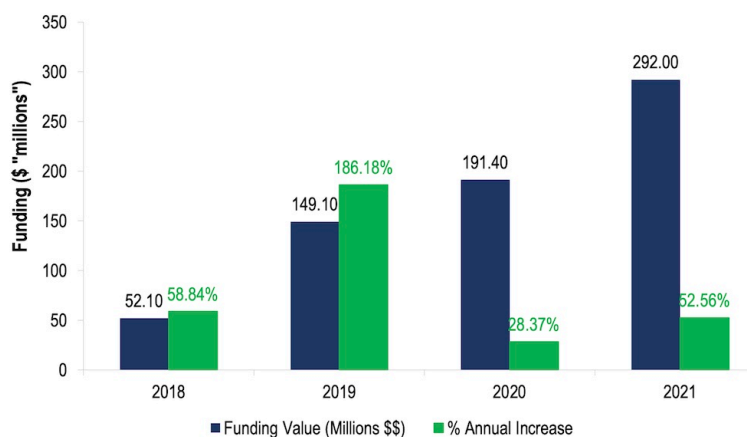
2.5.1.6 Secondary: Funding

Kenya tech start-ups, primarily those in emerging digital technologies, have seen a steady rise in funding over the past few years rising from an estimated \$52.1 million in 2018 to \$292 million in 2021. A general upward linear trend with an overall 460% increase over the three-year period (see Figure 2.22).¹⁴¹ The ability of the businesses in the sector to continue to raise funds shows the confidence global funders are increasingly having on the emerging digital technology sector in Kenya.

Despite the apparent growth in emerging digital technologies applications in Kenya, the absence of significant R&D in the country, and indeed on the continent, has resulted in the majority of the applications deployed originating from outside Africa. As a result, they often lack contextual relevance, especially with regard to aspects of culture and infrastructure.¹⁴²

2.5.2 State of Maturity

The emerging digital technologies ecosystem was assessed to be at the **growth stage of maturity**, based on the analysis of each of the fundamental activities and the roles played by each of the actors. Looking at each of the fundamental activities, **the research dimension was assessed to be at the nascent stage** as explained in Table 2.13.



Source: *statista.com*

Figure 2.22 Funding raised by Kenya Tech Start-ups 2018-2021

¹⁴⁰ Arunda (2021)

¹⁴¹ Statista.com, www.statista.com/statistics/1279470/funding-value-secured-by-startups-in-kenya/

¹⁴² Oxford Insights and IDRC (2019)






Fundamental Activities	Stages			
	Ideation	Nascent	Growth	
 Education			√	<ul style="list-style-type: none"> • 52.4% of all universities offer an undergraduate programme providing a strong foundation for those who may go into the workforce related to emerging digital technologies or pursue further studies; • Only 12.7% and 6.3% offer related Masters or PhD programmes, respectively, a fraction of the number of undergraduate programme.
 Research		√		<ul style="list-style-type: none"> • As a fraction of total patents applied for and granted in 2021, emerging digital technologies (excluding GIS) accounted for only 10.75 and 8.3%, respectively; • Journal publications, based on locally based research in emerging technologies were relatively few.
 End use			√	<ul style="list-style-type: none"> • There is a strong market demand for and/or understanding of the potential uses of emerging digital technologies, especially as they have provided opportunities for Kenya to leapfrog legacy systems and offer services leveraging on the extensive mobile penetration.
 Linkages			√	<ul style="list-style-type: none"> • Numerous and growing number of formal linkages provided through support from incubators, accelerators, hubs, associations, conferences and workshops.
 Implementation			√	<ul style="list-style-type: none"> • Significant number of start-ups and established business offering new services and products based on the emerging digital technologies, especially AI, and increasingly IoT, big data/data analytics and blockchain; • Facilitative governance and regulatory framework; • Extensive infrastructure (mobile and fibre networks, data centres, under-sea cable connections) supporting deployment of the technologies.

Table 2.13: Maturity of the different levels in the Digital Emerging Technologies Ecosystem

2.5.3 Potential Areas of Collaboration






Fundamental Activities	Potential Collaboration	Objective
 <p>Education</p>	<ul style="list-style-type: none"> • Link with UK universities at post-graduate level; • Invest in infrastructure, connectivity, Open Education Resources (OER) curriculum-aligned education content, offline digital solutions and holistic education strategies; • Support for teacher training in digital and pedagogical skills. 	<ul style="list-style-type: none"> • Review and modernise post-graduate curricula to incorporate current knowledge on emerging digital technologies; • Build inclusive, sustainable and thriving digital learning ecosystems; • To equip the teachers with the necessary skills to leverage the current and emerging digital tools and enhance their professional practice.
 <p>Research</p>	<ul style="list-style-type: none"> • Leverage on UK strength on AI to significantly ramp up research and development of AI process and tools; • Support commercialization of research outputs. 	<ul style="list-style-type: none"> • The level of R&D in AI in the country is low. AI process and tools and primarily developed abroad and implemented/adapted in Kenya. Aim is to significantly increase the level of R&D in AI and other emerging digital tools; • Create new products and services,
 <p>End use</p>	<ul style="list-style-type: none"> • Mitigation of risks from emerging crypto-assets; • Practical use of digital ledger technologies (DLTs). 	<ul style="list-style-type: none"> • Significantly reduce the threat of financing of terrorists and money laundering through emerging (and poorly understood) crypto assets; • Use DLTs to tackle common problems including resiliency of supply chains, detection of counterfeits, etc.
 <p>Linkages</p>	<ul style="list-style-type: none"> • Strategic joint funding frameworks. 	<ul style="list-style-type: none"> • Target inclusive and emerging areas such as green energy, precision agriculture to attract youth, women and persons with disabilities.
 <p>Implementation</p>	<ul style="list-style-type: none"> • Provide support to public and private institutions cybersecurity; • Improve public data accessibility and analytics, especially in the public sector; • Support in development and implementation of appropriate, facilitative policies and laws; • Expansion of digital infrastructure. 	<ul style="list-style-type: none"> • As more digital emerging technology-based tools come online more personal and institutional systems (public and private) are at threat from cyber-attacks. Collaboration areas would seek to strengthen the resilience of the Kenya digital space; • Enable the government (and other entities) to provide timely information in support of evidence-based decision-making leveraging on public data repositories; • To realize the full benefits of emerging digital technologies while mitigating the risks from negative unintended secondary impacts, for example, increasing the digital divide; • Promote digital inclusion, lower data costs and support localized accessible content.

Table 2.14: Potential Areas of Collaboration within the Digital Emerging Technologies Ecosystem

3. Conclusions and Recommendations

3.1 Conclusions

Existence of a broad definition of ETs does not imply uniformity in different landscapes. The context of varying landscapes matter, hence primary ETs may differ. In Kenya, seven primary ETs were identified to be artificial intelligence, blockchain, internet of things, big data/data analytics, geographic information systems, biotechnology and nanotechnology. The ETs were found to impact several sectors of the economy primarily agriculture, education, financial services/business, health, information, communication and technology (ICT) and water and sanitation.

The key actors in different ETs may be broadly related in terms of operational sectors. However, different ETs have varied distribution of actors and levels of skills base. Application and maturity of ETs is not uniformly distributed across the various sectors. For example, education, research and end use of biotechnology in Kenya was found to be in growth stage compared to nanotechnology where all the fundamental activities are in ideation stage.

Levels of investment in ETs are not the same and they mainly differ with the interests of the key funders. Digital emerging technologies in Kenya have been attracting increased attention from funders locally and internationally. Similarly, the existence of policies, regulations and standards are not uniform for all ETs. Although most ETs are not well understood and do not have defined functional processes and structures, some like biotechnology are at a stage where actors follow standard practices, policies, and procedures which are well known, and can be replicated and scaled.

There are various opportunities for collaborations on ETs ecosystem between Kenya, UK and South Africa. These include capacity building, joint research, technology transfer programs, specific ET policy and innovation accelerator programmes, and business engagement opportunities.

3.2 Recommendations

The following recommendations are made to favourably position Kenya's ETs landscape:

- i. **Explore and collate existing research and evidence, capacity and resources** to enable reflection, capacity strengthening and open avenues for collaboration and knowledge sharing between industry and academia in Kenya, South Africa and UK.
- ii. **Incentivize ongoing (and seek new) national and international partnerships in ETs.** Kenya should enhance the matching efforts on ETs programmes to tap and strengthen partnership opportunities with UK and South Africa through existing and upcoming ETs initiatives. This will enable indigenization of the ecosystem for local context-driven and globally informed solutions.
- iii. **Support ET activities and practices with favourable procedures and policies** that are routinely reviewed to adapt to changing global environment.
- iv. **Increase knowledge exchange, collaborations and networking forums between Kenya, UK and South Africa academia, industry and business community.** The creation of an ETs knowledge hub would support the collaborating countries to share values and interests and build closer relationships for shared policy and learning on product development in the ETs space.

References

- Adriano, A. (2021), "Technological Innovation is Fueling the Resurgence of Community Currencies.", *International Monetary Fund*, <https://www.imf.org/external/pubs/ft/fandd/2021/03/technological-innovation-fueling-community-currencies-adriano.htm> viewed April 2, 2022.
- Alumiro, LH (2015) *Direct Somatic Embryogenesis of Selected Commercial Coffea Arabica L. Varieties in Kenya*, Unpublished Masters Thesis, JKUAT.
- Arunda, Benjamin (2021), The Impacts of Emerging Technologies in the Future of Law and Legal Practice: A Case of Kenya. *Journal of CMSD* 6(2).
- Bandewar, SV, Wambugu, F, Richardson, E, and Lavery, J, (2017) "The role of community engagement in the adoption of new agricultural biotechnologies by farmers: the case of the Africa harvest tissue-culture banana in Kenya", *BMC Biotechnology*, 17, Article 28.
- Beumer, K, (2015), "The co-production of nanotechnology and development in India, South Africa, and Kenya" in *Practices of Innovation and Responsibility - Insights from Methods, Governance and Action* (p 85-98), Berlin: IOS Press, Editors: D.M. Bowman, A. Dijkstra, C. Fautz, J. Guivant, K. Konrad, H. van Lente, S. Woll.
- Cossy-Gantner A, Germann S, et al. (2018) "Artificial intelligence (AI) and global health: how can AI contribute to health in resource- poor settings?" *BMJ Global Health* 3:e000798.
- Cozzens, S. E., Gatchair, S., Kang, J., Kim, K.-S., Lee, H. J., Ordonez, G., and Porter, A. (2010). Emerging technologies: quantitative identification and measurement. *Technology Analysis & Strategic Management*, 22(3):361–376.
- East African Community (EAC) (2021) *The East African Regional Bioeconomy Strategy*, Arusha: EAC.
- European Commission (2018). "Artificial intelligence for Europe." <https://www.european-cources.info/record/communication-artificial-intelligence-for-europe/>
- Garousi, V, Felderer, M, Mantyla, V, "The Need for Multi-Vocal Literature Reviews with Grey Literature", *Proceedings of the 20th International Conference on Evaluation and Assessment in Software Engineering*, p. 26, ACM, 2016.
- Gatebe, E, (2012) "Nanotechnology: The magic bullet towards attainment of Kenya's Vision 2030 on industrialization" *Journal of Agriculture, Science and Technology*, 14 (2), 1-2.
- German, MS (2017) *Hybrid Anion Exchange Nanotechnology (HAIX- Nano) for Concurrent Trace Contaminant Removal with Partial Desalination: Laboratory and Field-Scale Investigations*, Unpublished PhD Dissertation, Lehigh University.
- Hansen, MB, Abràmoff, MD, Folk, JC, Mathenge, W, Bastawrous, A, and Peto, T (2015). "Results of automated retinal image analysis for detection of diabetic retinopathy from the Nakuru Study, Kenya." *PloS One*, 10 (10), e0139148.
- Haskew J, Rø G, Saito K, et al. (2015a) Implementation of a cloud-based electronic medical record for maternal and child health in rural Kenya. *International Journal of Medical Informatics*, 84:349–54.
- Haskew J, Ro G, Turner K, et al. (2015b) "Implementation of a Cloud-Based Electronic Medical Record to Reduce Gaps in the HIV Treatment Continuum in Rural Kenya." *PLoS One*, 10:e0135361
- Holmström O, Linder N, Kaingu H, et al. (2021) "Point-of-Care Digital Cytology With Artificial Intelligence for Cervical Cancer Screening in a Resource-Limited Setting." *JAMA Netw Open*; 4(3):e211740.
- Hung, S.-C. and Chu, Y.-Y. (2006). Stimulating new industries from emerging technologies: challenges for the public sector. *Technovation*, 26(1):104–110.
- Islam, M-S, Callicott, KA, Mutegi, C, Bandyopadhyay, R and Cotty, PJ (2021), "Distribution of active ingredients of a commercial aflatoxin biocontrol product in naturally occurring fungal communities across Kenya," *Microbial Biotechnology* 14 (4), 1331–1342.
- ITU (2021) [*Emerging Technologies \(AI\) Challenges and Principles of Regulation*](#)
- Jackson, T (2018), "Kenya's Twiga Foods partners IBM for blockchain-based microfinancing" *Disrupt Africa*, <https://disrupt-africa.com/2018/04/19/kenya-s-twiga-foods-partners-ibm-for-blockchain->

- [based-microfinancing/](#), Viewed April 2, 2022.
- Jackson, T (2019) “Kenya’s Shamba Records uses blockchain, AI to improve farm processes”, *Disrupt Africa*, <https://disrupt-africa.com/2019/08/12/kenya-s-shamba-records-uses-blockchain-ai-to-improve-farm-processes/>, viewed April 2, 2022.
- Jackson, T (2019b) “Agri--tech startup Hello Tractor to expand across Nigeria, Kenya”, *Disrupt Africa*, March 4, <https://disrupt-africa.com/2019/03/04/agri-tech-startup-hello-tractor-to-expand-across-nigeria-kenya/> viewed April 3, 2022.
- Kabunga, NS, Dubois, T, Qaim, M (2011) *Information Asymmetries and Technology Adoption: The Case of Tissue Culture Bananas in Kenya*, Discussion Papers, No. 74, Georg-August-Universität Göttingen, Courant Research Centre - Poverty, Equity and Growth (CRC-PEG), Göttingen
- Kahwai, J, Mburu, JI, Oulu, MO, and Hutchinson, MJ (2021), “Willingness to Pay for Hexanal Technology among Banana Farmers in Meru County, Kenya”, *International Journal of Food Science* Volume 2021
- Karembu et al, (2009)
- Kathurima, TM and Ateka, EM (2019), “Diversity and Phylogenetic Relationships of Full Genome Sequences of Cassava Brown Streak Viruses in Kenya”, *Biotechnology Journal International*, 23 (3), 1-11.
- Kosgei, CJ, Obonyo, MA, Matasyoh, JC, Owuor, JJ, Ollengo, MA, and Irungu, BN (2021), “Synthesis of Silver Nanoparticles Using Dichloromethane Extract of *Chrysanthemum cinerariaefolium* and Its Bioactivity” *International Journal of Applied Nanotechnology Research*, 6 (1)
- Martin, B. R. (1995). Foresight in science and technology. *Technology Analysis & Strategic Management*, 7(2):139–168.
- Mgala, M (2020), The Extent and Use of Artificial Intelligence to Achieve the Big Four Agenda in Kenya. *Multidisciplinary Journal of TUM* 1 (1) 2020 1-7.
- Mgala, M. and Mbogho, A. (2015). Data-driven Intervention-level Prediction Modeling for Academic Performance. *Proceedings of the Seventh International Conference on Information and Communication Technologies and Development*, 2:1–2:8.
- Milugo, TK, Omosa, LK, Ochanda, JO, Owuor, BO, Wamunyokoli, FA, Oyugi, JO, and Ochieng, JW (2013), “Antagonistic effect of alkaloids and saponins on bioactivity in the quinine tree (*Rauvolfia caffra* sond.): further evidence to support biotechnology in traditional medicinal plants” *BMC Complementary and Alternative Medicine*, 13:285.
- Ministry of Industrialisation (2012), *Sessional Paper No 9 of 2012 on the National Industrialisation Policy*.
- Ministry of Information, Communication and Technology (ICT) (2019), *Emerging Digital Technologies for Kenya: Exploration and Analysis*, Kenya, July 9, The Taskforce Report.
- Mtui, GYS (2011) “Status of biotechnology in Eastern and Central Africa” *Biotechnology and Molecular Biology Review* 6(9), 83-198
- Mwagira-Maina, S, Runo, S, Wachira, L, Kitur, S, Nyasende, S, Kemei, B, Ochomo, E, Matoke-Muhia, D, Mbogo, C and Kamau, L (2021) “Genetic markers associated with insecticide resistance and resting behaviour in *Anopheles gambiae* mosquitoes in selected sites in Kenya” *Malaria Journal*, 20:461.
- Mwangi, EK (2013) *Development of nanotechnology-based fungicide for sclerotinia stem rot, a soybean pathogen*, Unpublished PhD Thesis.
- Ndambiri, H and Rotich, E (2018) “Valuing excess fluoride removal for safe drinking water in Kenya”, *Water Policy* 20, 953–965.
- Ndung’u, 2019. “Digital Technology and State Capacity in Kenya.” *CGD Policy Paper 154*. Washington, DC: Center for Global Development.
- Odame, HS (2014) *Innovation Dynamics and Agricultural Biotechnology in Kenya*, Unpublished PhD Dissertation, Erasmus University Rotterdam.
- Odundo, J, Noah, N, Andala, D, Kiragu, J, Masika, E (2018) “Development of an Electrochemical Nano-biosensor for Rapid and Sensitive Diagnosis of Bilharzia in Kenya” *South African Journal of Chemistry*, 71, 127-134.
- Organisation for Economic Co-operation and Development (OECD) (2019a).

- “Recommendation of the Council on Artificial Intelligence.” *OECD Legal Instruments*.
<https://legalinstruments.oecd.org/en/instruments/OECD-LEGAL-0449>.
- OECD (2019b) *Regulatory Effectiveness in the Era of Digitalization*.
- OECD (2020) *The Impact of Emerging Technologies on Economic Regulators*. OECD Publishing, Paris.
- Ogawa, R and Malen, R, (1991) “Towards Rigour in Reviews of Multi-Vocal Literatures: Applying the Exploratory Case Study Method”, *Review of Educational Research*, 61(3):265-286.
- Okeyo, WA, Saarman, N., Mengual, M, Dion, K, Bateta, R, Mireji, PO, Okoth, S, Ouma, JO, Ouma, C, Ochieng, J, Murilla, G, Aksoy, S, and Caccone, A (2017) “Temporal genetic differentiation in *Glossina pallidipes* tsetse fly populations in Kenya.” *Parasites Vectors* 10, 471.
- Omwoyo, WN, Melariri, P, Gathirwa, JW, Oloo, F, Mahanga, GM, Kalombo, L, Ogutu, B, Swai, H (2016) “Development, characterization and antimalarial efficacy of dihydroartemisinin loaded solid lipid nanoparticles” *Nanomedicine: Nanotechnology, Biology and Medicine*, 12, 801-809.
- Oxford Insights and International Development Research Centre (IDRC) (2019). *Government Artificial Intelligence Readiness Index 2019*.
<https://www.oxfordinsights.com/ai-readiness2019>
- Oxford Insights and IDRC (2020). *Government Artificial Intelligence Readiness Index 2020*.
<https://www.oxfordinsights.com/government-ai-readiness-index-2020>.
- Oxford Insights and IDRC (2021). *Government Artificial Intelligence Readiness Index 2021*.
<https://www.oxfordinsights.com/government-ai-readiness-index2021>.
- Padh H, Aduda, BO and de Alwis. (2011), *Nanotechnology: Present Status and Future Prospects in Developing Countries*, New Delhi, Centre for Science and Technology of the Non-Aligned and Other Developing Countries.
- Poole DL and Mackworth AK. *Artificial Intelligence: Foundations of Computational Agents*, Cambridge University Press, 2010.
- Rotolo, D. and Martin, B. (2015) What is an emerging Technology, *Research Policy*, December.
- Saidi, T and Sigauke, E (2014), “Nano Visions and Challenges: The Case of Sub-Saharan Africa” in *Nanotechnology: Recent Trends, Emerging Issues and Future Directions*, Ed. Islam, N, New York: Nova Science Publishers.
- Templier, M and Pare, G. (2015) “A Framework for Guiding and Evaluating Literature Reviews.” *Communications of the Association for Information Systems*, 37.
- Wandera, BO, Onyango, DM and Musyoki, SK (2022) “Hepatitis B virus genetic multiplicity and the associated HBV lamivudine resistance mutations in HBV/HIV co-infection in Western Kenya: A review article.” *Infection, Genetics and Evolution*, 98.
- World Health Organisation (2020) *World Malaria Report 2020*.

Appendix A. Emerging Technology Ecosystem Maturity Model

A.1 Introduction

A maturity model makes possible the analysis of the state of development of an ecosystem. The model developed enabled the study team to answer the following questions: What impact have these technologies had? What is the level of investment in these technologies? How is Kenya aligning itself to be a global player? How are these ET shaping society and the economies of Kenya overtime? What factors have helped or hindered growth of ET in Kenya? What are the key gaps in the ETs?

A.2 Innovation Systems Approach

A country's economic development is tied to its capacity, embodied in its National Innovation System (NIS), to acquire, absorb, disseminate, and apply modern technologies. The NIS can be viewed as the collective of regulations, institutions, human capital, and government programmes that seek to link science and technology to the country's economy.¹⁴³ More formally, it can be defined as " ... that set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create store, and transfer the knowledge and skills and artefacts which define new technologies."¹⁴⁴

In the age of globalisation, it is still important to analyse innovation systems within national boundaries as although capital readily flows across borders, tacit knowledge is more difficult as it is embodied in our brains. It is much more difficult to move people across borders. Arguably the most crucial factors for innovation are human capital, government regulations, public and quasi-public institutions, and natural resources, all factors that are less mobile across borders.¹⁴⁵

Innovation system models can also be used in the context of specific technologies as the technologies

shape their own innovation systems as contexts necessary for further development of technological innovations. Referred to as a technology specific innovation system, it can be defined as "a network of agents interacting in the economic/industrial area under a particular institutional infrastructure ... and involved in the generation, diffusion, and utilisation of technology."¹⁴⁶ For example, a triple helix model of the innovation system was used to form an understanding of the biotechnology sector in Oxfordshire, UK.¹⁴⁷

The concept for technology specific innovation systems, was elaborated upon by Lundvall who posited that, "... it is useful to think in terms of 'technological systems' as a special version of innovation systems ... a combination of interrelated sectors and firms, a set of institutions and regulations characterizing the rules of behaviour and the knowledge infrastructure connected to it."¹⁴⁸

There are several accepted models for analysing IS. The most widely used is the *triple helix model* that focusses on actors in the innovation system, and is formed by three interconnected strands of university, government and industry. The model enables the exploration of the complexity and depth of the innovation process as an interactive, recursive system underlying a knowledge-based economy¹⁴⁹. Function-based models have also been proposed. For example Hekkert et al.¹⁵⁰ proposed a six function IS model: entrepreneurial activities, knowledge development, knowledge diffusion through networks, guidance of the search, market formation, resources mobilisation, creation of legitimacy/counter act resistance to change.

The approach adopted for this work is a system-level approach that enables development of an understanding of how "fundamental activities of the innovation process are organised, distributed and

¹⁴³ Sarewitz (2003)

¹⁴⁴ Metcalfe (1995)

¹⁴⁵ Feinson (2003)

¹⁴⁶ Carlsson and Stankiewicz (1991)

¹⁴⁷ Smith and Sharmistha (2010)

¹⁴⁸ Archibugi and Lundvall (2001)

¹⁴⁹ Leydesdorff and Zawdie (2010)

¹⁵⁰ Hekkert et al (2007)

coordinated.”¹⁵¹ The framework is based on *five fundamental activities*, research (basic developmental, engineering), implementation (manufacturing, deployment), end-use (customers of the product or process), linkage (bringing together complementary knowledge), and education (see Table A.1).¹⁵² The model includes primary actors, secondary actors, and institutions as key elements of the innovation system and are categorised based on their relationship with the five fundamental activities and each other. Descriptions of each of these model elements are presented next.

Research: Embodies basic (university/research institute mainly), development (university/research institute and industry) and engineering research (industry mainly). To achieve international competitiveness in ET, R&D must be able to reverse engineer, tailor technologies to suit customer needs and keep up with international trends. Also, universities must strengthen their role in technology transfer.

Fundamental Activities	Primary Actors	Secondary Actors
<i>Education</i> (knowledge and graduates)	Organisations that perform one or more of the five fundamental activities.	Organisations that affect the behaviour of or the action between primary actors. Can be direct (eg through mandates, regulations) or indirect (eg through policies, incentives.)
<i>Research</i> (basic, developmental and engineering)		
<i>Implementation</i> (production and commercialisation)		Institutions
<i>End-Use</i> (customers of the product or process outputs)		Are a set of practices, rules or organisation that guides or constrains and actor's behaviour.
<i>Linkages</i> (bringing together complementary knowledge)		

Table A.1: Classification of Actors in the Innovation System in the Fundamental Activities Model¹⁵³

A.3 Fundamental Activities

Education: In the context of emerging technologies, university level education is essential to monitor and assess global developments in the different technologies and be able to assimilate and implement new paradigms locally.¹⁵⁴ Universities also provide the ecosystem with a continuous stream of new knowledge (for example, publications and patents) and new carriers of knowledge (students).¹⁵⁵ The universities create “qualified personnel [in the emerging technologies] who can monitor technological and other trends, assess their relevance to the prospects for the country and individual firms, and help to develop strategy for reacting to and taking advantage of trends.”¹⁵⁶

End use: The consumers of the developed products and services. Ranges from individual consumers to society at large. For example, strong and visible changes in the preferences of society can influence the setting of R&D priorities and thus the technological change direction.¹⁵⁷

Linkages: Linkages between actors has been shown to be essential for successful innovation, diffusion, and exploitation.¹⁵⁸ It plays a central role in information exchange especially in within an IS where “R&D meets government, competitors, and market ... policy decisions (standards, long term targets) should be consistent with the latest technological insights and ... R&D agendas should be affected changing norms and values.”¹⁵⁹ Effective linkages with the IS remains a challenge in developing countries. For example, a study conducted in Ghana found that weak interaction between university, private sector and government actors as the major cause of failure

¹⁵¹ Liu and White (2001, p 1094)

¹⁵² Ibid

¹⁵³ Developed from Liu and White (2001)

¹⁵⁴ Feinson (2003)

¹⁵⁵ Leydesdorff and Zawdie (2010)

¹⁵⁶ Dahlman and Nelson (1995, p 97)

¹⁵⁷ Hekkert et al. (2007)

¹⁵⁸ Liu and White (2001)

¹⁵⁹ Hekkert et al (2007, p 423)

of development programmes despite adequate funding.

Also, poor coordination and coherence in the development and implementation of policies have also hindered the promotion of innovation.¹⁶⁰ In Kenya, according to the United Nations Industrial Development Organisation (UNIDO), there are very weak linkages between the research institutions and business enterprises, coupled with low innovativeness in business enterprises. Also, knowledge-based institutions (for example, universities and research institutes) have highly restricted outlets, through intermediation and commercialisation, to demand markets; have poor market intelligence; and are insufficiently aware of market needs. Finally, strategic research development activities in research institutions are not well aligned to the needs of medium and high technology industries.¹⁶¹ Government can and should play key role in facilitating coordination and collaboration between the system actors.¹⁶²

Implementation: Involves the conversion of research (knowledge), linkages (networks) and end use (markets) to exploit new business opportunities. The key actors are the entrepreneurs, the startups (new entrants with a vision for new businesses), and existing businesses (diversifying their business strategy to take advantage of new developments and opportunities). Entrepreneurial activity provides the main indicator of the performance on an IS. A lag in entrepreneurial activity can like be traced to causes within the other four fundamental activities.¹⁶³

New technologies often find it difficult to compete with existing entrenched technologies. Strategies must often be implemented to support diffusion of the new technology into the market. These could include the formation of interest or advocacy groups that seek to influence the acceptance of the new technology.

A.4. Actors and Institutions

Primary Actors: These are organisations that perform one or more of the five fundamental activities and include governments, universities, research institutes, and private enterprises. They also include

¹⁶⁰ Dzisah (2009)

¹⁶¹ UNIDO (2014)

¹⁶² Hou (2017)

¹⁶³ Hekkert et al (2007)

bridging institutions that act as intermediaries (linkages) between the different actors, for example, research councils and associations that act as intermediaries between research organisations and the government,¹⁶⁴ science and technology parks, incubators and accelerators.

Secondary Actors: These include government, for example, relevant government ministries/departments/agencies (MDAs) should enact facilitative Foreign Direct Investment (FDI) policies and strong intellectual property rights to provide an incentive for multinational companies to conduct research locally;¹⁶⁵ directly funding research and financing exploitation of the research; and establishing a favourable regulatory environment.¹⁶⁶ Other main secondary actors are funding institutions primarily in support of implementation activities, for example banks, equity funds, venture capitalists, and angel investors.

Institutions: Captures the norms, rules and environment that influences the decisions and actions of system actors.¹⁶⁷ They include the political establishment, including Parliament and the Judiciary who determine, for example, the extent of democratic governance or the tolerance for and the nurturing of a culture of corruption, both of which can serve as barriers to innovation.¹⁶⁸

Use of these models should recognise that they should be appropriately adapted in a developing country context as “the low demand for scientific knowledge from the side of the productive sector, the predominance of state-driven basic research and industrial driven applied research, the scarce investments in national industries in R&D as well as the profile of higher education institutions, more inclined to train professionals rather than supporting scientific research, leads to a configuration where NIS are not likely to emerge naturally.”¹⁶⁹ The same sentiment applies to technological innovations systems analysed with a national reference frame.

The fundamental activities model was used as the basis to assess the state of maturity for each of the

¹⁶⁴ Feinson (2003)

¹⁶⁵ Feinson (2003)

¹⁶⁶ Smith and Sharmistha (2010)

¹⁶⁷ Lundvall et al (2006)

¹⁶⁸ Razak and White (2015)

¹⁶⁹ Vasen (2011; cited in Delvene and Thoreau, 2012)

emerging technology's innovation system. The model of maturing is described next.

A.5 Maturity Model for an Emerging Technology Innovation System

The stage of maturity or the development stage models of an ecosystem serve to provide tools for assessment of where an ecosystem is in its life cycle. It provides insights into current level of success factors that have been recognised to be essential for the maturity, health, and sustainability of the ecosystem. For example, Ecosystems Connections Mapping Project developed a model to establish the development stage of localised start-up ecosystems. It defined three development stages (nascent, advancing, and mature) based on a set of measurable metric linked to the dimensions of community, skills, supporting infrastructure, invest, and constraints. The World Bank used the methodology to assess the development stages of the start-up ecosystems in several cities including Bogata, Dar es Salaam, Cairo, London, New York, and Singapore.¹⁷⁰

entrepreneurial support, corporate, academia, and government.¹⁷¹ A maturity model for software start-up ecosystems was developed with four stages of development namely, nascent, evolving, mature, and self-sustaining. These stages can be assessed along eight dimensions: exist strategies, entrepreneurship universities, angel funding, culture values for entrepreneurship, specialised media, ecosystem data and research, ecosystem generations and events.¹⁷²

This study employed the five fundamental activities and their attendant primary and secondary actors as the basis for analysing the development stage or maturity level of the ecosystem. From the literature, potential indicators are presented in Table A.2. Measurement, however, is a challenge as the data is not readily available. A survey of primary and secondary actors, grouped as researchers, startup/businesses, policymakers, and funders, was therefore conducted. A copy of the surveys are provided in Appendix C.

Three developmental stages of maturity were defined as ideation, nascent and growth. From the definition

Fundamental Activities	Potential Indicators ¹⁷³
Education	Quality of graduates (measured by quality or availability of hires), New Masters and PhDs, university post-graduate programmes, researchers/professionals engaged in R&D, Africa/global ranking of universities with post-graduate relevant programmes, policies,
Research	Related Publications, R&D projects, patents, availability of funding for R&D, pilot projects, availability of required equipment, policies,
End use	Government targets, industry targets, demand from government, demand/opportunities in the market, demand/opportunities beyond the borders, policies,
Linkages	Technology dedicated workshops and conferences, network size, network intensity, collaboration with academia (or with private sector),
Implementation	New entrants, diversification activities of incumbents; availability of funding (traditional, equity, venture capitalists, angel investors), interest groups, policies.

Table A.2 Potential Indicators to assess the state of maturity of each category of fundamental activities

The International Telecommunications Union developed an ecosystem maturity model whose development stages followed the entrepreneurship cycle, namely, pre-idea and culture, ideation, start-up, valley of death, and SME. These stages can be assessed along five dimensions linked to key stakeholders, namely entrepreneurs, finance,

of ET as being “radically novel” and “relatively fast growing” whose emergent phase is “uncertain and ambiguous” it is not practical to talk about a mature development stage (the end point in the above referenced examples.) By the time the ET ecosystem reaches a mature stage, the technology will no longer be considered emerging.

¹⁷⁰ World Bank (2017)

¹⁷¹ ITU (nd)

¹⁷² Cukier (2017)

Ideation: This stage is mainly characterised by R&D activities with pilots and proof-of-concepts also being carried out on potential commercial applications. It is beyond basic research on fundamental principles.

Nascent: Embodies the very early stages of the ecosystem development and formation. Characteristics include extreme ambiguity driven by uncertainties in technology, competition, structures and demands. They general still lack governance structures and clear guidance on value propositions (the value to create, who to create it for, and how to create it) as well as the structures for value creation and value capture.¹⁷³ Commercial ventures have been formed and sales have begun.

Growing: The commercial applications of the technology are gaining strong acceptance in the market with increase demand and new entrants. The ecosystem governance structures are starting to become clearer.

The characteristics of each of these stages, based on the indicators presented in Table A.2 are listed in Table A.3. They form the basis of the analysis and determination of the stage of maturity of each of the identified ETs.

Fundamental Activities	Ideation	Nascent	Growth
Education	Few Masters and PhDs, small number of academic departments, small number of researchers engaged in related research	Increased number of Masters and PhDs, small number of academic departments, increasing number of researchers engaged in related research	Large number of Masters and PhDs, increased number of academic departments, increasing number of researchers engaged in related research
Research	Few or no patents, small number of publications, few pilot projects, low research funding, few policies supporting related research	Increased number of patents, increased number of publications, increased number of pilot projects, moderate research funding, strengthened policies supporting related research	Increased number of patents, large number of publications, large number of pilot projects, adequate research funding, strengthened policies supporting related research
End use	Insufficient demand information for potential products and services, market size	Better understanding of and increasing demand for potential products and services, market size	Good understanding of and robust demand for potential products and services, market size
Linkages	None or few international connections (research); few linkages, no clusters.	None or few international connections (research and business); few linkages, no clusters.	Moderate international connections (research and business); moderate linkages and clustering;
Implementation	No active start-ups or existing businesses who have diversified into the ET space;	A few active start-ups or existing businesses who have diversified into the ET space but are in the early stages; none or very few start-up exists; establishment of governance framework; gaps in financing	Moderate number of active start-ups or existing businesses who have diversified into the ET space, with moderate number of scale ups; facilitative governance framework; increasing private sector financing

Table A.3: Stages of Maturity in the Emerging Technology Innovation System

¹⁷³ Dattee et al (2018), Moeen et al (2020)

References

- Archibugi, D and Lundvall, BA (Eds.), (2001) *The Globalizing Learning Economy*, Oxford University Press.
- Budden, P and Murray, F (2017) *A systematic approach for assessing innovation driven entrepreneurship in ecosystems* Working Paper, MIT Laboratory for Innovation Science and Policy.
- Carlsson, B and Stankiewicz, R (1991) "On the nature, function and composition of technological systems" *Journal of Evolutionary Economics*, 1(2):93-118.
- Commission for University Education (CUE) (2021) *Approved academic programmes offered in chartered universities in Kenya in accordance with the Universities Act*, Nairobi
- Cuiker, D (2017) *Software Startup Ecosystem Evolution: A maturity model*, Unpublished PhD Thesis, University of Sao Paulo.
- Dahlman, C and Nelson RR (1995) "Social Absorption Capability", in *National Innovation Systems and Economic Development in Social Capability and Long Term Economic Growth*. Eds. B Koo and D Perkins, 82-122.
- Dattee, B, Alexy, O and Autio, E (2018) "Maneuvering in poor visibility: how firms play the ecosystem game when uncertainty is high maneuvering in poor visibility." *Academy of Management Journal* 61(2), 466–498.
- Delvene, P and Thoreau, F, (2012) "Beyond the 'Charmed Circle' of OECD: New Directions for Studies of National Innovation Systems" *Minerva*, 50: 205-219.
- Feinson, S (2003) "National Innovation Systems Overview and Country Cases", in *Synthesis Report on the Findings of a Project for the Global Inclusion Program of the Rockefeller Foundation*. New York: Rockefeller Foundation.
- Hekkert, MP, Suurs, RAA, Negro, SO, Kuhlmann, S, and Smits, REHM, (2007), "Functions of innovation systems: A new approach for analysing technological change" *Technology Forecasting and Social Change*, 74: 413-432.
- Hou, J, (2017) *Development of national knowledge systems to support the knowledge economy development in low and middle-income countries: A literature review*, Overseas Development Institute.
- International Telecommunication Union (ITU) (nd) *Ecosystem maturity map: diagnosing and ecosystems health*.
- Kirira, P, Maina, N, and Mwitari, P, (2021) "Azadirachta indica Bark Extract Silver Nanoparticle Anticancer Formulation," *Kenya Industrial Property Journal*, No 2021/06.
- Leydesdorff, L, and Zawdie, G (2010). "The triple helix perspective of innovation systems." *Technology Analysis & Strategic Management*, 22(7), 789-804.
- Liu, X and White, S (2001), "Comparing innovation systems: a framework and application to China's transitional context", *Research Policy*, 30, 1091-114.
- Lugasi, S., "Enhancement of the red light luminescence from (E_uW₁₀O₃₆)⁹⁻ Anion" *Kenya Industrial Property Journal*, No 2021/05.
- Lundvall, BÅ, Intakumnerd, P, Vang, J (2006) *Asian Innovation Systems in Transition*. Cheltenham: Edward Elgar.
- Metcalfe, J. S. (1995). "Technology systems and technology policy in an evolutionary framework." *Cambridge Journal of Economics*, 19(1), 25-46.
- Moeen, M, Agarwal, R and Shah, SK (2020) "Building industries by building knowledge: uncertainty reduction through experimentation, knowledge release and knowledge acquisition" *Strategy Science* 5(3), 147-291.
- Razak, AA and White, G (2015) "The Triple Helix model for innovation: A holistic exploration of barriers and enablers." *International Journal of Business Performance and Supply Chain Modelling*, 7 (3), 278-291.
- Sarewitz, D (2003) "Knowledge Flows and Knowledge Collectives: Understanding the Role of Science and Technology Policies in Development", in *Synthesis Report on the Findings of a Project for the Global Inclusion Program of the Rockefeller Foundation*. New York: Rockefeller Foundation.
- Smith, HL and Sharmistha, B-S (2010) "Triple helix and regional development: a perspective from Oxfordshire in the UK" *Technology*

Analysis & Strategic Management, 22 (7), 805-818.

United Nations Industrial Development Organisation (UNIDO) (2014), *Kenya National System of Innovation: Measurement, Analysis and Policy Recommendations*.

Wasomi, C, Waitthaka, E, Kuria, D, Mwenda, D, and Gachari, M. (2021) "System for optimising multivariate contextual cartographic content in location based navigation service" *Kenya Industrial Property Journal*, No 2021/06.

World Bank (2017) *Tech Start-Up Ecosystem in Dar es Salaam: Findings and Recommendations* Washington DC: World Bank

Appendix B. Key Organisations

B.1 Government – Ministries, Departments and Agencies (MDAs)

1. Central Bank of Kenya
2. Communication Authority
3. Data Protection Commission
4. ICT Authority
5. Kenya Agricultural and Livestock Research Organization
6. Kenya Medical Research Institute
7. Kenya National Innovation Agency
8. Kenya Plant Health Inspectorate
9. Kenya Veterinary Vaccines Production Institute
10. Ministry of Agriculture
11. Ministry of Education
12. Ministry of Health
13. Ministry of Information and Communications Technology (ICT) and Innovation
14. National Biosafety Authority
15. National Commission for Science, Technology and Innovation
16. National Research Fund
17. The National Treasury and Planning

B.2 Universities

18. Dedan Kimathi University of Technology
19. Egerton University
20. Jomo Kenyatta University of Agriculture and Technology
21. Kenyatta University
22. Maseno University
23. Moi University
24. Multimedia University of Kenya
25. Technical University of Kenya
26. University of Nairobi

B.3 Private Sector, SME and Start-up Support

27. Association of Country-wide hubs
28. Association of Startup and SMEs Enablers of Kenya

29. Kenya Association of Manufacturers
30. Kenya Private Sector Alliance
31. Small and Medium Enterprises (SME) foundation

B.4 Development Partners

32. Foreign Commonwealth and Development Office
33. Gates Foundation
34. German Agency for International Cooperation - GIZ
35. Rockefeller
36. United States of Agency for International Development

B.5 Investors

37. Chandaria Capital
38. Kepple Africa Ventures
39. TLcom Capital
40. Villgro Africa

B.6 Foundations

41. Africa Medical and Research Foundation - Health Africa
42. Centum Foundation
43. Equity Foundation
44. Kenya Commercial Bank Foundation
45. MasterCard Foundation
46. Safaricom Foundation

Appendix C. Survey Instrument to Key Actors

C.1 Researchers

1 Which of the following emerging technologies is your research based on?

- Biotechnology Nanotechnology AI, Blockchain,
Internet of Things Geographic
Information
Systems

2a What stage are you in your academic/research career?

- Early career Mid-Career Late Career

2b Please select your gender?

- Female Male

3a How many journal publications do you have directly related to your chosen emerging technology?

3b Please indicate any regular locally workshops or conferences with a focus on your selected emerging technology (leave blank if there are none)?

4 Which sectors of the economy does your research target (select all that apply)?

- Agriculture Education Finance/Business
Services Health Manufacturing
- Other: _____
-

5 What stage is your current research activities (select all that apply)?

- Just starting Ready for
publication/
published Carried out proof
of concept pilots Ready for
deployment/
Commercialisation

6a Are you collaborating with industry in your current research activities?

- Yes No

6b Have you collaborated with industry in your past research activities?

- Yes No

- 7a Are you collaborating with other universities/research institutes in your current research activities?
- Yes No
- 7b Have you collaborated with other universities/research institutes in your past research activities?
- Yes No
- 8a Have you patented any of your research related to the selected emerging technology?
- Yes No
- 8b Are you likely to file for a patent for your current research activities in the next one year?
- Yes No
- 9a Do you have research funding for your current research activities?
- Yes No
- 9b If you answered yes, from which source (select all that apply)?
- Government Local foundation Foreign foundation Development partner Other
- 9c To what extent are sources of research funding available for your work?
- There are no sources of funding There are a few sources of funding I am not sure There are adequate sources of funding There are plenty of sources of funding
- 10 What are the **three biggest** challenges (in order) you face in carrying out your research on your selected emerging technology?
-
- 11a Are you currently teaching post-graduate students in the area of the emerging technology you have selected?
- Yes No

11b If answered yes, how would you rate, on average, the quality of these students (ability to grasp the concepts, think independently, carry out quality supervised research)

- Very poor Poor Acceptable Good Very Good

Please select an answer that reflects the extent you disagree or agree with the following statements

11 I have the necessary equipment/tools to carry out research work in the area of my selected emerging technology.

- Strongly disagree Disagree Neutral Agree Strongly agree

12a Current government policies are supportive of research on and applications of my selected emerging technology.

- Strongly disagree Disagree Neutral Agree Strongly agree

12b What policies would you like to see in place to support the development and application of your emerging technology?

13 There are an adequate number of researchers in the country required for the further development and application of my selected emerging technology.

- Strongly disagree Disagree Neutral Agree Strongly agree

C.2 Start-ups and Business

- 1 Which of the following emerging technologies are you exploiting in the products and services you offer?
- Biotechnology Nanotechnology AI, Blockchain, Internet of Things Geographic Information Systems
- 2 Which option best describes your business?
- Early stage start-up (less than 5 years old) developing/ offering product service based on selected emerging technology Start-up (more than 5 years old) developing/ offering product service based on selected emerging technology Established business developing/ offering product service based on selected emerging technology Other
-
- 3 Please select your gender?
- Female Male
- 4 Please indicate any regular local workshops, conferences or trade events that you (or employees within your business) attend that have a focus on your selected emerging technology (leave blank if there are none)?
-
- 5 Which sectors of the economy does your product/services target (select all that apply)?
- Agriculture Education Finance/Business Services Health Manufacturing
- Other: _____
-
- 6 How would you rate the market opportunity for the product or services you are developing based on your selected emerging technology?
- Very small Small Moderate Large Very large
- 7a If you are already selling your product or service based on your selected emerging technology, has the demand (as reflected by sales) met your expectation? Demand is
- Far below our expectations Below our expectations Meeting our expectations Above our expectations Far above our expectations
- 7b Which choice best describe your gross month-on-month **revenue (sales)** over the past two years?
- Sharply dropping Dropping Flat Increasing Sharply

increasing

- 7c Which choice best describe your gross month-on-month **net profits** over the past two years?
- Sharply dropping Dropping Flat Increasing Sharply increasing
- 7d What is the extent of demand from government for the products or services your offer based on your selected emerging technology?
- None Very low Low Moderate High
- 7d Do you have any sales of your product or service based on your selected emerging technology outside Kenya?
- Yes No
- 7e If yes, which countries?
-
- 8a Is your business collaborating with universities/research institutes in the development of your product or service based on your selected emerging technology?
- Yes No
- 8b Is your business collaborating with other business in the development of your product or service based on your selected emerging technology?
- Yes No
- 9a Have you patented any of the technology that the product or service you offer is based on?
- Yes No
- 9b Are you likely to file for a patent for the technology that the product or service you offer is based on in the next one year?
- Yes No
- 10a Do you have external funding to develop and grow your business?

Yes

No

10b If you answered yes, from which source (select all that apply)?

- Family and friends Loan from financial institution Local Investor (venture capital, angel investor, etc) Foreign Investor (venture capital, angel investor, etc) Local foundation
- Foreign foundation

11 To what extent are sources of funding available to develop and grow your business?

- There are no sources of funding There are a few sources of funding I am not sure There are adequate sources of funding There are plenty of sources of funding

12 What are the **three biggest** challenges (in order) you face in carrying in developing and growing your business based on your selected emerging technology?

Please select an answer that reflects the extent you disagree or agree with the following statements

13 I have the necessary equipment/tools to develop and grow in the area of my selected emerging technology.

- Strongly disagree Disagree Neutral Agree Strongly agree

14 Current government policies are supportive to the development and growth of my business based on my selected emerging technology.

- Strongly disagree Disagree Neutral Agree Strongly agree

15a What policies are in place that support the development growth of your business based on your selected emerging technology?

15b What policies would you like to see in place to support the development growth of your business based on your selected emerging technology?

15c What policies are in place that hinder the development growth of your business based on your selected emerging technology?

16 My business has many competitors in the market offering similar products and services based on my selected emerging technology.

- Strongly disagree Disagree Neutral Agree Strongly agree

C.3 Policymakers

1 Which of the following emerging technologies does your organisation set policies and regulations for?

- Biotechnology Nanotechnology AI, Blockchain, Internet of Things Geographic Information Systems

2 Please list some of the recent policies or regulations developed governing your selected emerging technology?

3 What is the current state of implementation of these policies and regulations?

4 What are some of the challenges faced in the implementation of these policies and regulations?

C.4 Funders

1 Which of the following emerging technologies does your organisation fund or invest in (select all that apply)?

- Biotechnology Nanotechnology AI, Blockchain, Internet of Things Geographic Information Systems

2 Which option best describes your organisation?

- Venture Capital Angel Investor Accelerator Development agency/ Foundation/ Non-profit organisation Other _____

3 What is your organisations typical level of investment in or funding of startups/businesses in Kenya?

- < \$10,000 <\$100,000 <\$500,000 < \$ million > \$1 million

4 Based on your organisations selection criteria of which businesses invest in or fund, which option best describes the number of businesses that meet or exceed the criteria?

- Very few A few Moderate number Many Very many

5 Please provide three common reasons why your organisation choses not to invest or fund a business that was under consideration?

Appendix D. Accelerators, Incubators and Hubs Supporting ET

Incubator/ Accelerator	Overview
<p>Agri-Business Incubation (ABI) and Start-up Centre, Egerton University</p> <p><u>ET supported:</u> Biotechnology</p>	<p>The Agro-science Park's mandate is to provide infrastructure and incubation space for transforming innovative ideas into new agro-products and services for commercialization in partnership with the industry. This has created new business opportunities and added value to agro-products. The basis for this park was because the University has a long tradition of agricultural training and research in the region. The park hosts the Agribusiness Incubation Centre and Start-up Centre.</p> <p><i>Services Offered:</i> The services include an Agri-Business Incubation (ABI) Centre and Start-up Centre where new business ideas and best practices is nurtured and tested for up-scaling and possible pilot testing and funding by industry and business companies.</p> <p><i>Performance:</i> Agro-Science Park has made several milestones which are mainly related to accelerating and facilitating scientists to commercialize Research innovations and products and link them with Industry. Some of these products include; Plant based mosquito Larvicide, release and commercialization of high yielding crop varieties, Commercialization of Egerton University Organic Honey and Yogurt, establishment of Fingerlings Production Unit. Also the University has established Biogas production system using cow-dug.</p> <p><i>Funding Model:</i> The University is collaborating with several donors and international organization to achieve this goal.</p>
<p>C4DLab, University of Nairobi</p> <p><u>ET supported:</u> AI, Blockchain and IoT</p>	<p>The C4DLab is a prototyping and innovative start-up incubation lab established by the School of Computing and Informatics founded in 2013,</p> <p><i>Services Offered:</i> Start-up Acceleration – The lab has a capacity of 10 physical start-ups, and unlimited number of start-ups engaged via the virtual incubation model. Capacity Building and Training – The lab runs seminars, boot camps and workshops geared towards building the capacity for the community to innovate; Prototyping – The lab engages in building in-house products.</p> <p><i>Performance:</i> Since inception more than 12 prototypes of very innovative products have been made. Notably among them are apps to analyse public transportation data and Games for Learning (G4L), which are mainly targeting primary school kids. In addition, there are currently eight physical start-ups incubated, with over thirty graduate since inception.</p> <p><i>Funding Model:</i> Fees paid by incubatees as well as grant funding.</p>
<p>Chandaria Incubation and Business Centre, Kenyatta University</p>	<p>The centre was launched in July 2011 to support new and innovative ideas from Kenyans. The centre accommodates both Kenyatta University Students and other Kenyans in need of support. It also promotes a culture of innovation among Kenyan youth through various programmes and a platform to provide solutions to challenges facing various industries. The centre aims at blending applied research with innovation and establishment of start-ups as well as predisposing Kenyatta University students and Kenyans at large to be job creators rather than job-seekers.</p> <p><i>Services Offered:</i> The centre offers design thinking and lean start-up training, Business Basics, Marketing, Financial Management, access to bank loans, loan funds and guarantee programs. Moreover, entrepreneurs are linked to strategic partners, get access to angel investors or venture capitalists; comprehensive business training programs, advisory boards and mentors, Technology commercialization assistance, assistance with regulatory compliance and</p>

Incubator/ Accelerator	Overview
	<p>intellectual property management.</p> <p><i>Performance:</i> The centre was highlighted as the most promising university incubator in 2014 in Stockholm, Sweden. A total of 12 start-ups have been incubated, fully registered and seeking investors. An additional Sixty-six (66) start-up ideas are being incubated with the help of various mentors.</p> <p><i>Funding Model:</i> Funding received from various local and international partners notably the Chandaria Foundation, The Youth Enterprise Development Fund (YEDF) and National Council for Science and Technology (NCST).</p>
DeHUB,	<p>DeHUB is an incubation centre whose main aim is to increase the wealth of its community, by promoting the culture of innovation and the competitiveness of its associated businesses and knowledge-based institutions. Dedan Kimathi University Innovation and Incubation Centre (DeHUB) was officially launched on 16th March 2015 by Dr. Fred Matiangi (Cabinet Secretary ICT).</p> <p>DeHub supports all start-ups incubated at the centre to produce quality products, help the founders penetrate the market and equip them with skills and knowledge to remain relevant in the market. Its Research Unit publishes research papers on new knowledge and the use of existing knowledge in a new and creative way so as to generate new concepts, methodologies and new understandings on various trends that enlighten start-ups and help them make right decisions in regards to their products, the market and investments.</p> <p>Besides the Incubation program, DeHUB has established a vibrant community of innovators to engage in weekly programs that involves business talks, technical meet-ups and/or consultations and creative' sessions. In addition to this, they do organize regular events in collaboration with key players in the industry and students' clubs aimed at enhancing members' knowledge and skills, challenging their potential and giving exposure.</p> <p><i>Performance:</i> Since its inception in 2015, DeHub has managed to incubate various innovative ideas and among the products that have been made are; Hakiki App which empowers consumers to verify whether the products they are using are from legit manufacturers or not; Autohomes Afrika which enables the owner of a house to easily control and monitor the house system when away; Nelion Farm which is a system that monitors a greenhouse by accurately regulating the conditions best fit for the particular crop.</p> <p><i>Services Offered:</i> These include newsletter; networking and other business events; specialist seminars and workshops; permanent desk space with WIFI and access to rest of DeHUB; discounted rates for meeting space; member of DeHub's job network; assistance with road mapping, marketing and intellectual property; access to executive advisors, investor and mentor network; full access to the professional services providers</p> <p><i>Funding Model:</i> Primarily membership fees charged to incubates. Fees vary depending on desired services.</p>
IbizAfrica, Strathmore University <i>ET supported:</i> AI, Blockchain and IoT	<p>Business incubator with a focus on ICT solutions. It carries out the entrepreneurship and incubation theme of @iLabAfrica. Moreover, it seeks to provide a nurturing environment that builds on the potential of the youth to develop ICT solutions and businesses. The incubator focuses being a focal point for investors to engage potential technology entrepreneurs, fostering an environment for entrepreneurs to develop, nurture and exchange their ideas, providing incubation facilities and establishing linkages with other incubation centres in the country and around the world and lastly forging partnerships.</p> <p><i>Services Offered:</i> Mentoring, business training, seed capital, and legal advice. Additionally, @iBizAfrica offers dedicated space and Pitch days for the Entrepreneurs.</p> <p><i>Performance:</i> Some of the ideas successfully incubated at @iBizAfrica are M-Ledger, a powerful MPESA analytics app; Purpink, an online gift shop specializing in customized gifts; Buymore, an app that allows students to enjoy discounts and merchant stores and brands they have partnered with; Eliteways Travel which focuses on tours and travel.</p> <p><i>Funding Model:</i> Key to the business model of iBizAfrica is forging partnerships with local and</p>

Incubator/ Accelerator	Overview
	international private sector players, for example Deloitte, CIO East Africa, and IDEA Foundation. In addition funds received from membership fees.
<p>@iLabAfrica, Strathmore University</p> <p><i>ET supported:</i> AI, Blockchain and IoT</p>	<p>Focuses on research, innovation and entrepreneurship. The research centre is involved in interdisciplinary research, students' engagement, as well as collaboration with government, industry and other funding agencies. They seek to provide an environment that promotes technological innovation, business support structures and policy direction to harness the potential of ICT as a genuine tool for sustainable development</p> <p><i>Services Offered:</i> ICT Research and Innovation, Incubation and Entrepreneurship and ICT policy Research. It also offers academic programs in Mobile Telecommunication and Innovation; short courses in ICT and the Barclays Ready To Work program which is designed to equip the youth with skills to enable them enter into gainful employment either as Entrepreneurs or employees.</p> <p><i>Performance:</i> Various projects have been developed among them the County Government Online Revenue Collection System, Health Projects, Data Visualization project in collaboration with Kenya National Bureau of Statistics (KNBS), Technology Projects, e-learning projects, engaging girls in Science, Technology, Engineering and Mathematics (STEM) and Project Autistech.</p> <p><i>Funding Model:</i> Partnerships with the Government, industry and other funding agencies.</p>
<p>iHub</p> <p><i>ET supported:</i> AI, Blockchain and IoT</p>	<p>Founded in 2010, iHub run by a local start-up community has been filling gaps in the local innovation ecosystems for a few years. They provide a part open community space, a part vector for investors and Venture Capitalists VCs, and part incubator. Their goal is to continuously fuel an ecosystem of innovation and technology that allows people to develop enterprises that creatively solve problems around them using technology.¹</p> <p><i>Services Offered:</i> mentorship, business support services, access to startup, product development related, workshops and events, venture funding, co-working space.</p> <p><i>Performance:</i> Have successful acquired several major partners including Facebook, Google, IBM, Fireside Group, SEACOM, Via Water, World Bank Group, Wananchi Group, Oracle, Safaricom, Make all voices count and Microsoft</p>
<p>NaiLab</p> <p><i>ET supported:</i> AI, Blockchain and IoT</p>	<p>Founded in 2011. An ICT Business Incubation Laboratory based in Nairobi Kenya, offers comprehensive incubation service and an outreach service that provides a simplified platform for innovators to be found by venture capitalists and business angels and investors for African profit and non-profit corporations.²</p> <p><i>Services Offered:</i> Business Incubation, Entrepreneurship program, Innovative technology driven ideas, co-working space.</p> <p><i>Performance:</i> Formed partnerships with VC4 Africa, SEACOM, Deloitte, AfriLabs, Yali Regional Leadership Center, Brand Integrated, 1% Club, Accenture</p>
<p>Lake Hub</p> <p><i>ET Supported:</i> AI, Blockchain and IoT</p>	<p>Lakehub is a technology innovation hub in Kisumu; an open space for entrepreneurs, technologists, investors and makers.³</p>
<p>Nakuru Box</p> <p><i>ET Supported:</i> AI, Blockchain and IoT</p>	<p>Provides co-working spaces, networking events, training, and incubation.</p>
<p>Science, Technology and Innovation Park,</p>	<p>Overall aim of the park is to provide quality space and environment to promote Science Technology and Innovation activities and business, to facilitate commercialization of innovative</p>

¹ iHub website: <http://www.ihub.co.ke>

² <https://yecomunity.com/en/countries/kenya/hubs>

³ <http://lakehub.co.ke/>

Incubator/ Accelerator	Overview
<p>Maseno University</p> <p><u>ET Supported:</u> Biotechnology</p>	<p>products and services from university research centers, to ensure collaboration and linkages of innovators with the industry to encourage need based innovations and to promote application of Science, Technology and Innovation in the service of community through appropriate outreach programs.</p> <p><i>Services Offered:</i> The Science, Technology and Innovation Park provides space and environment to promote cutting edge innovations, incubation and marketing of innovative products for regional and global competitiveness.</p> <p><i>Performance:</i> The Science, Technology and Innovation Park has developed a draft Science, Technology and Innovation Policy. Additionally, it has developed 4 new high yielding maize varieties. These hybrids have successfully undergone National Performance Trials and have been recommended for release. Of these, Maseno EH10 and EH11 were released by Ministry of Agriculture in June 2013. The seed Unit for the University currently known as Maseno University Seeds has also been registered and a draft business plan for the same developed.</p>