EMERGING TECHNOLOGIES IN SOUTH AFRICA A LANDSCAPE ANALYSIS

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EMERGING TECHNOLOGIES IN SOUTH AFRICA: A LANDSCAPE ANALYSIS AUTHORSHIP

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Executive summary

Technologies are increasingly pervasive across society. We use them to communicate, to prepare our food, in manufacturing, teaching, healthcare etc. Technologies change over time as improvements or radical new ways of doing things are found. This creates a space for what some term 'emerging technologies'; a set of technologies that are novel, gain momentum and have the potential to create new economic sectors and impact positively on development goals. These technologies span a range of different types and are not limited to those that are digital, include high-tech components or are research and development intensive.

In South Africa a landscaping and assessment of existing and future potential emerging technologies, to maximise the positive socio-economic and developmental impacts and mitigate against potential misuses and harms, is essential to ensure that future action complements existing interventions and is demand driven. As such, the FCDO-Eastern and Southern Africa Research and Innovation Hub engaged the University of Johannesburg's DSI/NRF/Newton Fund Trilateral Research Chair in Transformative Innovation, the 4th Industrial Revolution and Sustainable Development (UJ-TRCTI) to analyse and map emerging technology ecosystems in South Africa to gain an in-depth understanding of the landscape and context, enabling factors, risks, opportunities, and early precedents being set on use cases, governance and enabling environment. This recognises the role that South Africa plays as a regional technology leader and its likely ability to influence how these technologies are developed and used across Southern Africa.

This report outlines the results of this landscape analysis. It is based on an in-depth literature review, the analysis of a survey dataset of 262 firms in South Africa about their use of several emerging technologies, and over 20 key informant interviews across the academic, government and private sectors. A small validation workshop was also held where the results were discussed with a range of stakeholders.

This landscape analysis identified 20 emerging technologies being promoted, developed, deployed or used in South Africa. Of these, the top four can be divided between new emerging technologies (artificial intelligence and next generation health) and waning emerging technologies (mobile applications and e-commerce). These waning technologies are not disappearing but are becoming accepted and assimilated into processes and becoming a form of general purpose technology. This, and the fact that the analysis has identified low-tech and high-tech emerging technologies being promoted, developed and used across all stages of the production lifecycle, means that a clearer definition of 'emerging technology' is needed.

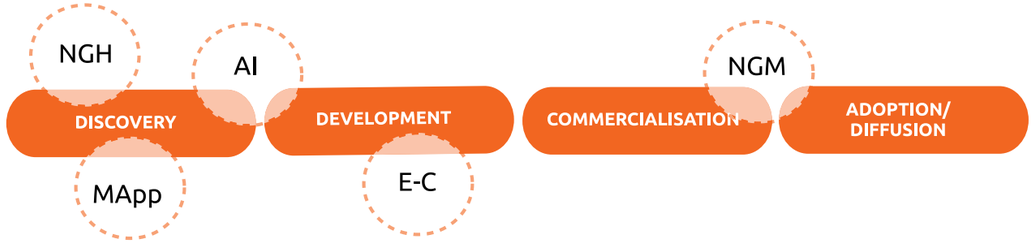
Recommendation 1: *A revised and more nuanced definition of emerging technologies, or a tiering of emerging technologies, would help ensure that the debate on emerging technologies is not dominated by a particular interest area (e.g., 4IR technologies) and that a broad spectrum of technologies receive attention.*

The use of roadmaps and strategies has been noted as ways to guide the development and diffusion of a few emerging technologies and sectors utilising emerging technologies. There are, however, no apparent roadmaps or strategic plans to guide the development of the top four emerging technologies identified. This is despite a significant level of activity taking place in these areas and a plethora of actors involved.

Recommendation 2: *UK agencies to hold consultations with relevant South African agencies (notably Department of Science and Innovation, the Council for Scientific and Industrial Research and the Technology Innovation Agency as well as relevant line ministries) on the benefits of developing roadmaps for top emerging technologies and supporting the production of these.*

It is noted that the top four emerging technologies appear to suffer from bottlenecks at different places along the production lifecycle. We identified these as bottleneck areas with very few projects active for each technology in these areas of the lifecycle (see figure below). While existing funders and actors are involved across these lifecycles, the bottlenecks highlight where more attention is needed.

Figure: Bottlenecks across the lifecycle for the four top emerging technologies



Source: authors. Notes: AI – Artificial intelligence; E-C – E-commerce; MApps – Mobile applications; NGM – New generation health

This is particularly pertinent for the waning emerging technologies. The fact that they are waning i.e., becoming accepted and normalised should not mean that they do not receive funding and support to continue technological innovation. This is particularly necessary given their potential as general purpose technologies of the future.

Recommendation 3: *UK agencies to work with South African counterparts to showcase the status of these emerging technologies with British firms and organisations to build partnerships to remove the bottlenecks.*

There is an increasing focus by the South African government and other actors on policy and regulatory issues relating to emerging technologies. This has been prompted by the country's focus on engaging proactively with the 4IR. However, the country still lags behind others on the continent in terms of digital skills, having a knock-on effect in industry on attitudes to new technologies (as noted in the survey results presented). Linked to this is a lack of comprehensive strategies and analysis on the risks of these emerging technologies. The UK has significant experience reviewing risks related to emerging technologies and one example, the UK's Digital Competition Expert Panel, was highlighted during the study as an example relevant to South Africa.

Recommendation 4: *UK agencies to work with members of the UK's Digital Competition Expert Panel and others to provide reflections on what has and has not worked in identifying and addressing emerging technology risks as part of South Africa's on-going efforts in this area while noting the contextual differences between the two countries.*

Contents

1. Background

Disruptive technologies including advanced robotics, artificial intelligence, big data analytics, cloud computing, the Internet of Things (IoT), smart sensors, augmented (AR) and virtual reality (VR), and 3D printing have begun to transform global manufacturing including South Africa's. At the same time, precision agriculture, aquaponics and vertical farming are new technologies – not all digital – that are starting to transform the agricultural space in South Africa. Such technologies are expected to result not only in greater efficiencies, leading to improved competitiveness, but also to trigger changes in traditional production relationships among suppliers, producers, and customers and, in the case of agriculture, to have less impact on the environment. These and other new emerging technologies are also expected to profoundly change the skills mix of different occupations and will impact the concentration of technologies in firms and sectors raising concerns in terms of the negative impacts that the adoption of 4IR and other emerging technologies may have on the national distribution of income and wealth. This is particularly important in a country like South Africa, which cannot afford higher inequalities and job losses, having one of the highest inequality levels in the world.

Against this background, the Foreign Commonwealth and Development Office (FCDO), through its Eastern and Southern Africa Research and Innovation Hubs and the Science and Innovation Network (SIN) teams, is supporting work to strengthen research and innovation ecosystems across both regions and the continent. They aim to work across the innovation value chain to complement existing FCDO Science Technology and Innovation (STI) programming to ensure enhanced coordination of activities to achieve a sustainable scale of effective STI solutions to developmental challenges in priority areas across Africa.

Recognising the increasing importance emerging technologies will have, a landscaping and assessment of existing and future potential emerging technologies, to maximise the positive socio-economic and developmental impacts and mitigate against potential misuses and harms in South Africa, is essential and will ensure that future programmes are additional and complementary to existing interventions and demand driven.

As such, FCDO-Eastern and Southern Africa Research and Innovation Hub engaged the University of Johannesburg's DSI/NRF/Newton Fund Trilateral Research Chair in Transformative Innovation, the 4th Industrial Revolution and Sustainable Development (UJ-TRCTI) to analyse and map emerging technology ecosystems in South Africa to gain an in-depth understanding of the landscape and context, enabling factors, risks, opportunities, and early precedents being set on use cases, governance and enabling environment. This is in recognition of the role that South Africa plays as a regional technology leader and their likely ability to influence how these technologies are developed and used across Southern Africa.

This report outlines the findings of the landscape analysis undertaken to review the status of emerging technologies themselves, the actors and networks involved as well as the institutional arrangements that support or hinder the development, deployment and use of these technologies. The report starts with an overview of the assignment scope and methodology in Section 2. It outlines the results in Section 3 and the recommendations and conclusions in Section 4. Annexes are provided to augment the findings where appropriate.

2. Analysis scope and methodology

This landscape analysis was conducted between January and April 2022 and focused on the following overarching objectives:

- To provide an in-depth analysis of the landscape of emerging technologies, where there is potential to maximise development impact in Southern Africa: their use, impact, trends and enabling factors; and where there are intentionally or not, ethical, social and economic risks and the gaps that need to be addressed. In addition to assess the impact in national but also regional innovation ecosystems.
- Based on an understanding of the landscape in South Africa, to explore and propose gaps as well as opportunities for partnership with the UK (either bilateral or multilateral as the evidence will guide) in both regions.

This study addressed these objectives using innovation studies thinking, notably, the sectoral innovation studies approach. Innovation refers, in its broadest sense, to the introduction of something new into an environment. This project studied the emerging technology landscape using a three-part innovation systems lens (c.f. Malerba, 2005):

Knowledge and technology: A sector is shaped by the dominant technologies, knowledge and skills base and inputs available to the sector. The degree of innovation in technologies and the strength of the knowledge base, and the availability of inputs will determine whether and how the sector grows or contracts in size.

This project investigated the following areas to understand the shape and size of this innovation system element:

- Number and type of emerging technologies being used or developed in South Africa
- The level of R&D occurring in this field
- The extent of skills and capabilities in South Africa to develop and make use of emerging technologies.

Actors and networks: private firms are central to innovation systems but interact with a range of actors, including public sector organisations (e.g., universities, research centres, government departments) and the third sector (e.g., non-governmental organisations or community groups) as individuals. Sectoral innovation occurs across a range of geographical boundaries as many sectors rely on inputs from sources not always local to them, including product supply firms or investors in other parts of the country or abroad. The quantity and quality of interaction – the level of networking taking place – determines the intensity and type of innovation that takes place. This networking may be formal or informal, bilateral and multi-lateral in nature and can involve the sharing of knowledge and skills and formal technology transfer or investment.

This project investigated the following areas to understand the shape and size of this innovation system element:

- A mapping of actors who are involved in the emerging technologies space in South Africa
- A list of actors who are not involved but should be involved in these activities based on the experiences of similar countries
- A discussion of partnerships and interrelationships between different actors and the existence of notable gaps in the innovation system connections.

Institutions: these are the 'rules of the game' both formal (e.g., legislation and policy) and informal (e.g., attitudes and norms) as well as dominant narratives that determine how actors and networks operate and interact.

[1]Hanlin, R. and Numi, A. (2020) The Relevance of Science, Technology and Innovation Studies: Linking Academia and Industry. AfricaLics Briefing Note. Available at: https://www.africalics.org/briefing-notes/ (accessed 15/12/21)

This project investigated the following areas to understand the shape and size of this innovation system element:

- A review of policy documents for relevant clauses and sections, together with examples of their use.
- A discussion of the dominant narratives that are evident in discussions of the emerging technology, 4IR and related fora in South Africa and how they are shaping what and who is involved in the innovation system, including the sectors of the economy where most emerging technology is being used or pushed for use.

In so doing, the project addressed the following research questions outlined in its Terms of Reference:

- What is the definition, status and types of technology defined as emerging technology, the actors, the key players across public, private and development partners including (start-ups, investors, academia, government etc); use cases and impact (if any), the distribution of these technologies in the different sectors; level of investments from South Africa and other partners in emerging technology?
- What role do regional organisations play (if any?) e.g., the African Union? How is South Africa aligning itself to other global players? What multilateral fora are they participating in or looking to join (e.g., Global Partnership for AI)?
- What factors have influenced the growth or lack of growth of emerging tech in Africa?
- Which government departments in South Africa are looking at emerging technology (coordination, implementation, etc)? What policies exist and what is the status of implementation (these could be strategies, policy directives, adopted standards such as the OECD AI)? What rules govern the use of emerging technology and protect citizens against harm? Any novel approaches being taken to set future regulation – i.e., models of anticipatory regulation?
- What are the risks to individual's privacy, repression, inequality and exclusion, power dynamics linked to asymmetric access to information, jobs and labour, barriers to market entry? Is there any analysis being done on socio-economic impacts (privacy, rights, access to services, jobs, access to markets) and steps being taken to reduce inequalities?
- Based on an understanding of the landscape in South Africa what are the key gaps in emerging technology? What is the role of the key actors? What are the opportunities for the UK to strengthen partnerships in each country? Are there opportunities for a trilateral partnership (South Africa, UK and Kenya) and how would this be structured (mutual areas of interest and activities; participating institutions/ actors etc) and propose gaps as well as opportunities for partnership with the UK (either bilateral or multilateral as the evidence will guide).

The project used a combination of desk review, interviews and analysis of a quantitative data set to answer these questions. Details of these methods including the data reviewed and interviews conducted are provided in Annex 1 and summarised here in Table 1.

Table 1: *Research methods*

METHOD	DETAIL
DESK REVIEW	Four separate desk reviews were conducted. Three of these focused on grey literature discussions around each of the three elements of the sectoral innovation system and one of these focused on academic literature. A sub-section of the desk review on institutional environment focused specifically on developing an understanding of the current policy landscape in South Africa.
INTERVIEWS	Semi-structured interviews ranging from 30 to 60 minutes were conducted with 22 individuals from academia (10 interviews), private sector (4 interviews) and government (8 interviews).
QUALITATIVE DATA ANALYSIS	Desk review and interview data were reviewed by the research team and key words and phrases were placed in a thematic matrix table. Thematic areas followed the sectoral innovation systems high level designations (technology/ knowledge, actors/ networks and, institutions) to which sub-themes were added as they arose.
QUALITATIVE DATA ANALYSIS	The report makes use of survey data on frontier technology adoption in South Africa collected in 2021 and 2022 from 262 formally registered firms in the service and manufacturing sectors across the country's nine provinces. The analysis uses simple non-parametric analysis techniques to understand frequency, quantity and type of emerging technology use. The data set also includes questions on policy and skills.

This study received University of Johannesburg ethics approval. The approval number is: 22SECO051

3. Landscape analysis findings

3.1 DEFINITION OF EMERGING TECHNOLOGY

This analysis used the Rotolo, Hicks and Martin (2015) definition of 'emerging technology' as the starting point for the review. Rotolo and colleagues reviewed the academic literature to understand how the concept of 'emerging technologies' was being defined and noted five core characteristics of these technologies:

1. Radical novelty – this is not necessarily always a radical new technology but a new application of the technology in a new combination or area of attention.
2. Relatively fast growth – the technology becomes popular i.e., gains attention from investors and potential users more quickly than other similar technologies.
3. Coherence – the technology becomes identifiable (from what came before it), and a set of actors coalesce around that technology.
4. Prominent impact – this may be in a particular domain or across multiple sectors.
5. Uncertainty and ambiguity – the technology is still evolving and will only be fully understood
(both in terms of process and outcome/ impact) in the future.

Such a definition does not lend itself well to a definitive list of technologies. In fact, Rotolo, Hicks and Martin (2015) clearly articulate that context matters and therefore what is seen as an emerging technology in one context will not necessarily be seen as an emerging technology in another.

Given the ambiguity of the concept – even with the framework outlined above – it is perhaps not surprising that, when a literature review was conducted for this report, it found that the concept of emerging technology also competed in South Africa with the concepts of 'frontier technology' and the 'fourth industrial revolution' related technologies. The Department of Science and Innovation (DSI) 2020-2025 Strategic Plan does however have an outcome statement that features emerging technologies: "Over the next five years, improve the sustainability and competitiveness of traditional sectors of the economy and initiate/continue research and development in emerging technology areas that could enable the creation of non-traditional South African economic sectors" (DSI, 2020: 47). This Strategic Plan focuses on the introduction and growth of technologies in new economic areas.

In addition, our desk review of grey and academic literature also identified that those writing about emerging technologies in South Africa do so across a range of sectors and include technologies which could be identified as 'low-tech' solutions i.e., do not require significant levels of research and design investment and are not 'knowledge intensive' in their development. It also includes those that do not only include digital or information communication related solutions and/or components e.g., aquaponics. Table 2 (Section 3.2.1) provides an overview of the final list of technologies that this report classified as 'emerging technologies' while Figure 1 highlights the sectors that emerging technologies are mostly used in. Interestingly we see a mismatch between the foci of attention by public and private sector organisations with public sector organisations focused predominately on 4IR technologies while the private sector is more focused on technologies that many might argue are no longer emerging if defined as only emerging in a product lifecycle sense i.e., at the first stages of design and development. However, the desk review conducted highlighted the use of the term 'emerging technology/ies' at all spectrums of the technology lifecycle (see Section 3.3). It is perhaps not surprising therefore that several interviewees questioned the definition of 'emerging technologies'. One interviewee (interview 8) suggested the use of the term 'general purpose technologies' as a more appropriate term. This term has been used since the mid-1990s to describe technologies that are important for a wide range of applications and linked applications (e.g., electricity is often given as an example of a general purpose technology). Such a definition focuses on the significance of the technology over the long run and not just its initial novelty and potential for impact as per Rotolo et al. (2015).

[2]For more on general purpose technologies see: Bekar, C., Carlaw, K. and Lipsey, R., 2018. General purpose technologies in theory, application and controversy: A review. Journal of Evolutionary Economics, 28(5), pp.1005-1033.

Given the above, this report finally utilised the following four overarching criteria for the definition of emerging technologies:

1. **Novelty or newness** in the context in which it is being used e.g., it is not a dominant technology used by many stakeholders in the sector but is attracting investment and interest.
2. This investment and interest are occurring at speeds not seen by other similar technologies and as a result **momentum** around the technology is growing.
3. The technology has the **potential to create new economic sectors** or stimulate existing ones and in so doing impact positively on the achievement of national social and economic development goals.
4. The technologies **span a range of different types** and are not limited to those that are digital or include high-tech components and are R&D intensive

3.2 AN INNOVATION SYSTEM ANALYSIS

The status of technologies that exhibit novelty, momentum and have potential for positive economic and social impact cannot be considered simply based on the technologies themselves. The success of a technology is dependent on the quantity and quality of knowledge (including skills) relating to that technology as well as the actors and networks that are involved. For a technology to proceed through the lifecycle also requires an enabling institutional environment with supportive policies and regulation but also attitudes, rules and norms. This multi-perspective approach to considering technology development benefits from an innovation systems analysis. Innovation systems refer to a way of analysing the lifecycle of a new technology by focusing on a wide range of factors influencing the uptake and use of the new technology, method or approach. This section focuses on the three key elements that make up an innovation system: technology and knowledge, actors and networks as well as institutions.

3.2.1 TECHNOLOGY AND KNOWLEDGE

Two key documents produced yearly are the go-to for lists of new technologies in South Africa, namely, the Technology Innovation Agency (TIA) and Council for Scientific and Industrial Research (CSIR) annual reports. For example, TIA produced 77 new technologies between 2015 and 2020 while CSIR recorded 48 new demonstrations in 2020-2021. A review of innovation, incubation and hacker spaces also highlighted a range of new digital technologies being developed and at various stages of commercialisation. However, not all new technology listed in these reports were digital or high-tech i.e., R&D intensive. They included new skin care ranges, environmentally friendly rat traps, new ways to fireproof housing and alternative methods to extract metals from waste materials; to name just a few examples.

In addition, the team conducted a frequency analysis of the reference to each technology across the desk reviews conducted. A total of 123 projects using emerging technologies were identified through the desk review (see Annex 5). The frequency analysis results fit with the list of technologies given to us by those interviewed for this report. Table 2 outlines the top 10 results of this analysis i.e. the technologies referenced the most as being the focus of attention of projects at various stages of the innovation lifecycle by either private sector or public sector actors. Thus, the results are split between the technologies mentioned in relation to public sector organisations and private sector firms in the grey literature and systematic academic literature review. The desk review did not identify every single government department, university or private sector company that works with, promotes or uses emerging technologies in South Africa. However, we are confident, given that we have captured data across 39 public sector and 82 private sector organisations, that we have a list that is typical of the foci of South African organisations.

The list of foci technologies defined as emerging in respect to the public sector organisations differs somewhat from those of the private sector (see Table 2). The most frequently mentioned emerging technology in the private sector is next generation (next gen) health while this is number four in the public sector. Top of the list in the public sector is 3D printing and artificial intelligence (AI). AI is fourth in the private sector column and 3D printing down at number 6.

The includes many of the emerging technologies listed in the South African White Paper on Science, Technology and Innovation of 2019. This list of 'emerging fields of knowledge, technologies and materials that will shape the near future' (DST, 2019: 18) is made up of: graphene (new material), regenerative medicine and medical geology, carbon capture and storage as well as modelling, simulation and gaming, quantum computing, artificial intelligence and virtual reality.

It also maps onto the list developed by the African Union High-Level Panel on Emerging Technologies (APET), established in 2016. APET has identified and prioritised ten emerging technologies of relevance for Africa's socio-economic development. These are: 1. Gene drives; 2. Microgrids (included under energy generation technologies in Table 2); 3. Drones for precision agriculture; 4. Next-generation medicine; 5. Artificial intelligence; 6. Urban agriculture; 7. Synthetic biology; 8. 3D printing; 9. Next-generation batteries (included in energy storage technologies in Table 2); and 10. Water purification.

Table 2: *Final list of top emerging technologies in South Africa*

TOP 10 TECHNOLOGIES ACROSS PUBLIC AND PRIVATE SECTOR	
EMERGING TECHNOLOGY	**FREQUENCY**
Next generation health	26
Artificial intelligence	23
3d printing	21
Energy storage solutions	18
Biotechnology	17
Water purification technologies	13
Hydrogen technologies	13
E-commerce technologies	11
Software/ mobile applications	10
Next generation agro-processing	9

TOP 10 TECHNOLOGIES ACROSS PUBLIC AND PRIVATE SECTOR				
#	**EMERGING TECHNOLOGY**	**FREQUENCY**	**EMERGING TECHNOLOGY**	**FREQUENCY**
1	Next gen medicine	26	3D printing	15
2	E-commerce	23	Artificial intelligence	14
3	Software/ mobile apps	21	Biotechnology	11
4	Artificial intelligence	18	Next gen medicine	11
5	Energy storage solutions	17	Hydrogen technologies	10
6	3D printing	13	Energy storage solutions	10
7	Biotechnology	13	Next gen agro-processing	8
8	Water purification	11	Water purification	8
9	Energy generation solutions	10	New materials	5
10	Automation	9	Synthetic biology	4

Source: *authors*

Table 2 reinforces the idea that what is determined as 'emerging technology' is not always new technology or that which is heavily digital or high-tech i.e., R&D intensive. In fact, 15% of the papers that were read in depth for the systematic literature review focused on non-digital and non-high-tech solutions and deemed them 'emerging'. This included ICT technologies and farming techniques such as aquaponics.

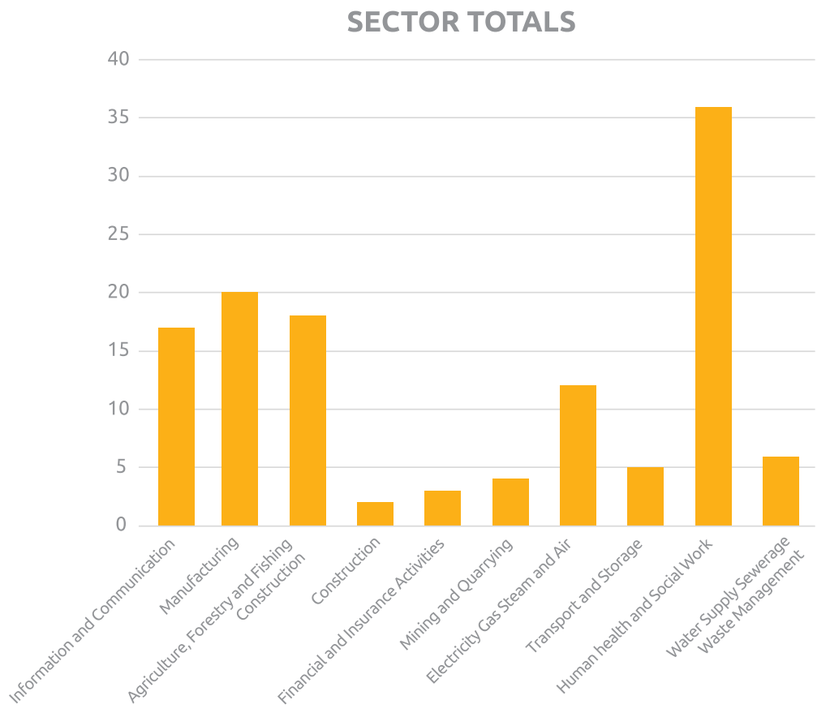
As noted by one interviewee (Interview 19) working in a field that spans biotechnology and next generation health (including diagnostic devices):

"What is emerging technology? I mean, this [their company's technology] is based now on 20 years technology that is around… so I would say that part is already established, and we do some, some test development [of new technology]"

The need to define 'emergence' as more than something new to the world, but also something that is new to a context, aligns with an increasing focus on innovation (as opposed to simply technology) and broader definitions of innovation that relate to the introduction of something new to an environment not simply as something that is commercialised for the first time (new to the world). The focus of the private sector on technologies that may already be seen as established e.g., e-commerce and mobile/ software applications reiterates this. In addition, during the stakeholder validation workshop a discussion was held on the importance of considering the end products and services that are developed and used as opposed to the base technologies that are used to make the products and services.

Figure 1 provides an overview of the sectors in which the 123 projects identified are situated.

Figure 1: *Distribution of emerging technologies by sector*



Source: *authors.*

NOTE: Sector definitions used are those by the UK's Office of National Statistics.

It is interesting to note that at least one interviewee noted the importance of not just considering the sector in which these emerging technologies were being used, but also the need for these technologies in different sectors. This interviewee (Interview 4) noted that an important focus must be on how these technologies solve problems and address issues of food security, transport and security challenges faced by society. A second interviewee (Interview 8) made a similar argument about the need to focus not on listing the 'top technologies' but the top challenge areas that need to be addressed in society (energy, social integration and sustainability issues).

A series of other issues were raised by interviewees regarding the status and direction of technology. These related to the convergence of technologies, technology acceptance, infrastructure to support technology and the focus of the country on the development and use of the technologies. This will be discussed in Section 3.2.4.

The technologies reviewed in this study are predominately those that have been designed and developed in South Africa as opposed to those that are commercialised in South Africa through licensing arrangements from technology producers in other countries. South Africa has a significant level of technology production, or rather, a high level of technology patenting. Table 3 outlines the number of patents granted in South Africa across the top emerging technologies identified by this study. It is noticeable to see that next generation health has a significantly larger number of patents filed than other technology areas. This is partly due to the wide-ranging search terms that had to be used. The next highest levels of patents are in the field of biotechnology, followed by energy storage solutions. We have very few patents for software/ mobile applications and e-commerce or for artificial intelligence.

Table 3. *All patents registered for emerging technologies in South Africa, excluding patents filed internationally under the Patent Cooperation Treaty system*

EMERGING TECHNOLOGY	PATENTS	SEARCH TERMS (APPLIED ACROSS ALL FIELDS)
Next generation health	24562	"medicine" OR "pharmaceutical"
E-commerce	145	"e-commerce" OR "electronic commerce"
Software/ mobile apps	280	"software application" OR "mobile application" OR "smartphone application" OR "mobile app" OR "software app" OR "smartphone app"
Artificial intelligence	108	"artificial intelligence" OR "machine learning" OR "fuzzy logic" OR "logic programming"
Energy storage solutions	3677	"energy storage" OR "batteries" OR "fuel cells"
3D printing	156	"additive manufacturing" OR "3D printing" OR "rapid prototyping" OR "additive technology" OR "three-dimensional print*"
Biotechnology	3909	"biotech*"
Water purification	2314	"water purification" OR "purified water" OR "purification of water"
Energy generation solutions	631	"energy genera*" OR "electric* generation" OR "solar power" OR "wind turbine"
Automation	21	"automation software" OR "automated software" OR "software automation" OR "process automation"

EMERGING TECHNOLOGY	PATENTS	SEARCH TERMS (APPLIED ACROSS ALL FIELDS)
Cloud computing	16	"cloud computing" OR "utility computing" OR "on-demand computing"
Imaging technologies	365	"optical imaging" OR "imaging tech*"
New materials	315	"new materials" AND NOT "nanotech*"
Drones	22	"drone" OR "unmanned aircraft vehicle" OR "unmanned aircraft" OR "remotely piloted aircraft"
Nanotechnology	67	"nanotech*" OR "nano-tech*" OR "nanoscale"
Next gen agro-processing	136	"agro-process*" OR "agro-product process*" OR "agri* processing" OR "post-harvest"
Synthetic biology	109	"synthetic biology" OR "synbio" OR "gene synthesis"
Gene drives	2031	"gene drives" OR "genetic engineering" OR "gene drive tech*"
Automotive technology	662	"automotive tech*" OR "vehicle tech*" OR "braking system" OR "suspension system" OR "vehicle manuf*"
Hydrogen technologies	81	"hydrogen tech*" OR "hydrogen fuel*" OR "hydrogen catalys*

Source: *https://patentscope.wipo.int/search/en/advancedSearch.jsf*

KNOWLEDGE, SKILLS AND CAPABILITIES

Annex 3 provides details of the research that is being conducted by universities and other research organisations in South Africa in relation to emerging technologies. Our interviewees all noted that universities and the research infrastructure in South Africa was strong, certainly stronger than many of its neighbours in Africa. However, there were mixed opinions as to whether the level of skills in the country were sufficient to enable the country to embrace emerging technologies.

One interviewee noted that they had been looking to appoint a programmer for four months and the position is still vacant. He explained that the reason was not because there are no programmers in South Africa, but because their field of focus (additive manufacturing) is new and emerging in South Africa and therefore, there is not a large base of experienced professionals to choose from.

That said, on the issue of technical skills to develop the technologies, the range of opinions included:

- 'We have some good graduates and master's with knowledge [required]' (Interview 20)
- 'Not that no PhDs, just no opportunities' (Interview 11)
- 'We have to train on the specific technology but finding good people is not difficult in South Africa' (Interview 119)
- 'There are skills in research but not innovation within the commercial, private sector' (Interview 15)

This last sentiment about the skills being taught at universities was echoed by three other interviewees too. A strong sentiment was that there is insufficient support for PhD students to start their own businesses (spin outs from university). This is despite, as one interviewee noted, that in South Africa any public sector organisation that conducts research and development must have a technology transfer office. Two interviewees noted that African universities have the wrong incentive structure in place with a focus on publications and not patents and commercialisation. Interviewees noted that the structures to support commercialisation were not only a problem in universities, but that there were difficulties to commercialise products across the board (the valley of death situation). This is discussed further in Section 3.2.3.

A third of the interviewees discussed the pipeline issue for skilled staff. The private sector interviewees all noted that there were skills available, although one noted the need to train further. Several interviewees noted that, while there have been improvements in basic education and the teaching of science, technology, engineering and maths (STEM) in schools in South Africa – two interviews discussed the introduction of robotics and coding into the national education syllabus from 2023 – this knowledge was still lacking as compared to other countries. One private sector interviewee noted that it was difficult to find staff to work for him with the skills he needed because they tend to have better opportunities abroad; that the country suffered from brain drain.

An internet search identified courses available in universities that focus on emerging technologies (Table 4). This is not an exhaustive list but corroborates interviewees that noted there are training programmes available specifically focused on emerging technologies. This is in addition to general training at undergraduate and post-graduate level in STEM subjects.

The study of e-commerce appears to focus mainly at the level of vocational and continuing professional development (CPD) courses. Many of these were set up in response to the COVID-19 pandemic that started in 2020. The University of Pretoria offers a range of online courses in e-commerce. Other universities also provide CPD courses in emerging technologies. For example, the University of Johannesburg offers CPD in AI and blockchain. In addition, several of the South African Sector Education and Training Authorities (SETA) have set up courses relating to 4IR technologies in the last couple of years. The Media, Information and Communication Technologies SETA (MICTSETA) set up 11 new courses in 2021: Artificial Intelligence, Cloud Computing, Cyber Security, Data Science, Design Thinking Lead, Design Thinking Practitioner, Internet of Things, Robotic Processing Automation, Quality Engineering Automation, Systems Development and e-Waste. The banking sector SETA has also started a cybersecurity course. The food and beverages SETA has provided training on digital marketing and operations in 2021. In addition, and as noted by a number of the interviewees, the South African government has partnered with Cisco Systems and Huawei to upskill technical vocational and training centre staff on digital skills including artificial intelligence, big data, cloud computing. That said, several interviewees noted that technical skills were only part of the problem facing businesses in South Africa and one interviewee (Interview 4) called for more soft skills and entrepreneurship training as well as technical training. This resonates with a larger literature on the difficulties of entrepreneurship in South Africa (and many other countries).

Table 4: University courses in emerging technologies

EMERGING TECHNOLOGY AREA	UNIVERSITIES
Artificial intelligence	Master's and PhD degrees (University of Johannesburg, University of Stellenbosch, University of Witwatersrand, University of Cape Town)
3D printing (materials engineering)	Master's and PhD degrees (University of Johannesburg, University of Stellenbosch)
Nanoscience	Since 2012 a joint master's degree in nanoscience and nanotechnology has been offered between University of Johannesburg (UJ), Nelson Mandela Metropolitan University (NMMU), University of the Free State (UFS), and the University of the Western Cape (UWC). Master's and PhD in Nanotechnology (Rhodes University)
Hydrogen fuel cells	PhD University of Cape Town
Biotechnology	Offered at undergraduate level as straight biotechnology or with a focus on plants, industrial or developmental biotechnology at 13 different universities in South Africa. Master's and PhDs also available at a number of different universities.

Source: authors

Several interviewees also noted that private companies had started their own training programmes. Sasol and Eskom were named by interviewees as having sent some of their employees for PhD training because they realised they needed to upskill their internal capacity.

Finally, over a third of interviewees noted the need to not just train researchers and those working in business to develop the technology but also communities to use the technology. The latest available digital skills indicators from the World Economic Forum show that South Africa has a rating of 3.27. These are basic computer skills, basic coding skills and digital reading skills where 1=not all and 7 = to a great extent. This compares to Kenya at 4.55, China at 4.66 and the Republic of Korea at 4.99. From this, it can be deduced that the digital skills in South Africa are quite low. Interviewees specifically focused on the work of the Department of Communications and particularly, NEMISA (National Electronic Media Institute of South Africa) who provide digital literacy training to individuals and government staff. This links to a broader issue discussed by the majority of interviewees with regards to the degree to which South Africa should be developing its own technology and not just importing new technology from elsewhere. See Section 3.2.4

3.2.2 ACTORS AND NETWORKS

This review identified a diverse sample of 216 actors and networks in the emerging technology space, including firms, global development agencies, financiers and investors, and government departments, agencies, bodies, and state-owned enterprises. However, the prevalence, configuration, and contribution of actors in the different emerging technology clusters varies, reflecting, in part, perceived opportunities and the size and maturity of the sector (or sectors) in which the technology can be applied. More details of actors and networks in these emerging technology areas are provided in Annex 2.

Universities and public research institutions are (and have been) active in both applied and basic research as well as teaching and learning. Their role has been discussed in some depth already in Section 3.2.1 and will not be discussed further here. A list of 28 universities and other research entities involved in emerging technology research is provided in Annex 2 (Table 2.1).

The role of several key state actors (Annex 2, Table 2.1) notably, the Department of Science and Innovation (DSI), the Council for Scientific and Industrial Research (CSIR), the Technology Innovation Agency (TIA) and the Industrial Development Corporation (IDC), is evident for advancing emerging technology development, uptake, and upscaling in South Africa (Table 5). These agencies were seen as key to the funding of research and commercialisation of technologies (DSI, CSIR, IDC) but also to provide direction in the development of technologies. For example, one interviewee mentioned the development by DSI of a roadmap for 3D printing (the South African Additive Manufacturing Strategy published in 2016). Roadmaps for emerging technologies that have been developed in South Africa by these actors and others include: the Waste to Energy Roadmap; Water Research, Development and Innovation Roadmap; and Hydrogen Society Roadmap.

Table 5: Key state actors in the South African emerging technology landscape

STATE ACTOR	DESCRIPTION
Department of Science and Innovation (DSI)	The national ministry responsible for the promotion and resourcing of science and innovation activities for increased wellbeing and prosperity in South Africa. In 2021 the Department changed its name from the Department of Science and Technology to DSI, to reinforce its focus on the promotion of innovative activities in South Africa. Current Minister (April 2022): Dr Blade Nzimande (Minister of Higher Education, Science and Innovation) Website: https://www.dst.gov.za
Council for Scientific and Industrial Research (CSIR)	*This is under the Department of Science and Innovation and is focused on conducting research, development and innovation of transformative technologies and accelerating their diffusion. It is also mandated to improve the competitiveness of high-impact industries.* *The CSIR focuses on nine clusters to deliver the desired impact, namely Advanced Agri and Food; NextGen Health; Future Production: Chemicals; Future Production: Mining; Future Production: Manufacturing; Defence and Security; NextGen Enterprises and Institutions; Smart Logistics; and Smart Places* *Current Chief Executive Officer (April 2022): Dr Thulani Dlamini* *Website: https://www.csir.co.za/*
Technology Innovation Agency (TIA)	TIA is a national public entity that serves as the key institutional intervention to bridge the innovation chasm between research and development from higher education institutions, science councils, public entities, and private sector, and commercialisation. TIA's focus is on technology development; from proof of concept to pre-commercialisation. The organisation's strategic goals include commercialisation support to commercialise technological innovations; infrastructure access to increase access to technology development; and stimulating an agile and responsive NSI. Current Acting Chief Executive Officer (April 2022): Mr Patrick Krappie Website: https://www.tia.org.za/

STATE ACTOR	DESCRIPTION
Industrial Development Corporation (IDC	The IDC was created in 1940 through an Act of Parliament (Industrial Development Corporation Act, 22 of 1940), and it is owned by the South African government. IDC priorities are aligned with the national policy direction as set out in the National Development Plan (NDP), Industrial Policy Action Plan (IPAP) and industry master plans. IDC's mandate is to maximise South Africa's development impact through job-rich industrialisation, while contributing to an inclusive economy by, among others, funding black-owned and empowered companies, black industrialists, women, and youth-owned and empowered enterprises. IDC supports industrial capacity development proactively by identifying and funding high-impact projects, creating viable new industries, and using diverse industry expertise to drive growth in priority sectors. This is to facilitate sustainable direct and indirect jobs; promote entrepreneurial development and grow the SME sector; and transform communities and grow black industrialists. Current Chief Executive Officer (April 2022): Mr Tshokolo Petrus Nchocho Website: https://www.idc.co.za

Source: *authors*

Several interviewees also mentioned the National Research Foundation (NRF) as important for funding research at universities which often involve private sector actors in research consortia too. Line ministries were also seen as important in pushing innovation and technology development forward in these emerging technology areas (notably the Department of Health, Department of Trade, Industry and Competition as well as the Department of Agriculture, Land Reform and Rural Development).

State actors appear to often play an early-mover role as research funders, investors and financiers, and developers of networks and alliances. However, interviewees differed in the degree to which they felt government should actively push innovation activities. One interviewee mentioned the Square Kilometre Array project as an example of the benefit of taking a mission-oriented approach to emerging technology development which builds specific capabilities in the country. Others noted that the 'red tape' to get funding and support complicated the usefulness of public funding (one interviewee noted it took two years to get to prototype stage because of the paperwork involved).

Only two interviewees mentioned the role of provincial and municipal governments in the emerging technology field. One mentioned work by the City of Johannesburg to promote green technology. Another interviewee mentioned a collaboration between DSI, MLab (a non-profit mobile applications laboratory) and the Limpopo provincial government to promote agricultural and tourism innovation in Limpopo (with funding from CSIR).

Incubators and innovation hubs as well as makerspaces and fabrication labs are also visible in this space. An overview of those most frequently mentioned in the desk review is provided in Tables 6 and 7.

Table 6: Top 10 incubators in South Africa

	INCUBATOR	DESCRIPTION
1	Small Enterprise Development Agency (SEDA) Incubators	three-year programme of incubation to strengthen technology commercialisation and harness the entrepreneurship of the technology community in South Africa. www.seda.org.za
2	Shanduka Black Umbrellas	Recognised for being one of the most successful incubators, Raizcorp grows and develops entrepreneurs. They have incubation programmes that include training, mentoring, and access to markets, finance and infrastructure.https://www.raizcorp.com
3	Raizcorp	Recognised for being one of the most successful incubators, Raizcorp grows and develops entrepreneurs. They have incubation programmes that include training, mentoring, and access to markets, finance and infrastructure.https://www.raizcorp.com
4	BizQube	BizQube works with corporate sponsors in the food, beverage, cosmetic and pharmaceutical manufacturing sectors to identify and develop opportunities in supply chains for start- ups or small businesses, who then enter an incubation programme. https://www.businessessentials.co.za/partner/bizqube
5	Timbali Technology Incubator	An incubator that connects low-skilled, young, inexperienced, unemployed rural people to markets through incubation. The programme provides an enabling environment through training, mentorship, technology packaging and financing facilitation amongst other things. https://www.timbali.co.za
6	The Innovation Hub	The Innovation Hub offers a number of incubation programmes in the Bioeconomy, Smart Industries (ICT) and Green Economy (water purification, waste management and renewable energy). In addition, The Innovation Hub operates a range of enterprise development, skills development and innovation enabling programmes both in the science park and throughout Gauteng. https://www.theinnovationhub.com
7	Awethu Projects	ecognised as the most innovative SMME investment company in Africa, Awethu Projects combine ideas, people and capital, to build fast-growing SMMEs in Africa, including informal traders. http://www.awethuproject.co.za
8	Launch Lab	Established by the University of Stellenbosch, their focus is on creating scalable high impact businesses. They provide resources, information and expertise through the university and investors. https://www.launchlab.africa
9	Startupbootcamp Afritech	The incubator supports early-stage tech founders to rapidly scale their companies by providing direct access to an international network of the most relevant mentors, partners, and investors in their industry. https://www.startupbootcamp.org
10	Tshimologong	Owned by the University of the Witwatersrand, the incubator provides support to digital entrepreneurs. Programmes offered include education, coaching, mentorship, experiential learning, financial and technical skills, and legal and governance. They also commercialise research conducted by Wits students. https://tshimologong.joburg

Source: *(https://youthvillage.co.za/2014/08/10-business-incubators-know/; https://getlion.co.za/business-incubator-program-in-south-africa; https://www.entrepreneur.com/article/327566; https://www.failory.com/startups/south-africa-accelerators-incubators; https://www.nexinstartups.com/business-incubators-in-south-africa/)*

Table 7: Makerspaces and Digital Fabrication Laboratories (FabLabs) in South Africa

	MAKERSPACE/ FABLAB	DESCRIPTION
1	The Maker space	Situated in Durban, the Maker space have 3D printers and lasercutters and share knowledge and equipment that enables people to make anything.bhttps://themakerspace.co.za/
2	Bloemfontein FabLab, Central University of Technology (CUT)	At the FabLab, there are multiple 3D Printers, lasercutter, vinyl cutting and general power tools available. The equipment can be used to produce or perfect prototypes. https://www.cut.ac.za/fablab
3	North West FabLab, North-West University Potchefstroom Campus	Ideas2Product (I2P) lab was established at the University to cater to the community, and not just students and staff. It has a 3D printer and other equipment. https://news.nwu.ac.za/
4	Sebokeng FabLab, Vaal University of Technology (VUT) Southern Gauteng Science Park	FabLab provides a platform where communities can have access to advanced tools that help people make products to address local needs. https://www.vut.ac.za/fablab/
5	Ekurhuleni FabLabs	The City of Ekurhuleni adopted the FabLab concept, to promote innovation and support entrepreneurship within disadvantaged communities, thereby reducing unemployment. https://www.fablabs.io/labs/ekurhulenifablabs
6	Limpopo FabLab, University of Limpopo Turfloop Campus	A community-based FabLab established to develop the innovative capability of Limpopo youth. https://www.fablabs.io/labs/limpopofablab
7	CDI Product Support Space, Craft and Design Institute (CDI)	The facility helps craft producers, designers, students, and other individual businesses develop new products and refine existing ones, assisting individuals in generating innovative products. https://www.thecdi.org.za/page/dev_product
8	eKasi Labs	eKasi (meaning at the township) Labs are micro-innovation hub facilities to foster innovation and entrepreneurship in townships. These labs are located at the townships in Mohlakeng, Sebokeng, Garankuwa, Soweto, Tembisa, Alexandra, Mamelodi, Kagiso, Kathorus and Mabopane. Entrepreneurs get assistance and support in commercialisation and market development, intellectual property and other legal service advisory and access to finance. https://www.theinnovationhub.com/business-incubators/ekasi-labs-4
9	University of Pretoria, Library Makerspace	The Makerspace is situated in the Merensky Library and is a space where students can make 3D prototypes of their ideas and get expert advice in the fields that they require. https://vimeo.com/141761175

Sources: *Schonwetter and Van Wiele (2020); https://libguides.unisa.ac.za/c.php?g=492401&p=3372538*

The private sector was mentioned by all interviewees as a key actor in these fields. Many interviewees noted that these emerging technology fields are not just the realm of large corporates but also many small and medium-sized firms. The industries that were mentioned most by interviewees as being engaged in emerging technology development or use were telecommunication firms, mining companies and banks/ insurance companies. More details on which private sector firms are working in this space is available in Annex 2 (Table 2.3).

The desk review highlighted that large listed firms and multinationals have greater visibility when emerging technologies have applications in existing markets or require significant capital expenditure e.g., British producer Lonmin Plc (its operational headquarters are in Johannesburg) investing in additive manufacturing for jewellery. Conversely, smaller, newer, and unlisted firms appear to have had opportunities where markets for new technologies are not established. Examples include ICT start-up Khula, creating apps for agriculture supply chains, the PACSys and DC Geomatics Joint Venture for precision agriculture utilising drones and AI for crop spraying.

Partnerships and collaborations were seen as essential, either to deal with funding gaps or to bring in capabilities where these are missing. Many of the university interviewees mentioned the importance of European research funding in this regard and its important role in building the capability of local South African researchers. One interviewee mentioned the African Development Bank as a key funding partner for emerging technology innovation while others mentioned the expected funding partners notably, NRF, IDC and venture capital. See Section 3.2.3 for more on the funding of emerging technology development and use. The desk review also identified that CSIR hosts the South Africa 4IR Centre. This has an official partnership with the World Economic Forum and is part of a network of similar centres around the world. It has a governmental remit to promote and develop governance and policy frameworks to enable South African businesses and government departments to better take up, utilise, and regulate these emerging technologies.

An overview of global collaborations that South Africa is part of is provided in Annex 2 (Table 2.4) and includes the following specific to emerging technologies: African Biosafety Network of Expertise (ABNE), African Biosciences Initiative (ABI), NANOsciences AFrican NETwork (NANOAFNET) and SmartAfrica. South African organisations are also part of various international partnerships and collaborations (see Annex 2, Table 2.5). The desk review identified 17 different partnerships and collaborations which covered many of the emerging technology areas in Table 2 (Section 3.2.1) notably 3D printing, agro-processing, drones and artificial intelligence.

No interviewee noted collaborations with UK companies. Several university-based interviewees noted research partnerships with UK universities and one private sector interviewee's firm uses UK and US firms' equipment with some linkage in terms of spare parts and training. However, the desk review revealed several examples of UK-based firms and organisations contributing to the development and commercialisation of emerging technologies in South Africa. These are provided in Table 8.

Table 8: *UK-based actors and networks visible in emerging technology in South Africa*

STAKEHOLDER	CAPACITY	DESCRIPTION
Aparito Limited	Investor	UK-based Aparito have developed a wearable device for remote long-term epileptic patient monitoring outside of the hospital. The technology developers are currently seeking partners to assist with market entry strategies into low- and middle-income countries and partners in the broader expansion of the technology in other therapeutic areas in South Africa.

STAKEHOLDER	CAPACITY	DESCRIPTION
Blue Prism Group plc	Partner	Blue Prism has partnered with South African company CLEVVA to provide an enhanced customer service product offering. Blue Prism is a British multinational software corporation that develops enterprise robotic process automation software. The partnership was announced in Feb 2021.
Cenfura Limited	Investor	Cenfura is a technology company integrating digital payments technology into the energy sector. The company is based in London, UK. In 2021 that the company entered into a joint venture with DNA Global Energy to deliver 14 new blockchain-based renewable energy microgrids across South Africa.
DNA Global Energy Limited	Investor	DNA Global Energy is an energy project development company based in London, UK. In 2021, the company announced a joint venture with Cenfura to deliver 14 new blockchain-based renewable energy microgrids across South Africa.
Global Sustainable Mobility Partnership	Network alliance	The Global Sustainable Mobility Partnership (GSMP) is a network of independent, not-for-profit expert organisations in the USA, UK, Europe and South Africa with extensive, practical and real-world experience supporting the delivery of low-emission mobility programmes.
The CDC Group	Investor	UK development finance institution, the CDC Group, and the Norwegian Investment Fund (Norfund) invested R600 million in H1 Capital, a South African black-owned and managed renewables investment and development company. The deal was announced in March 2022 to fund a pipeline of new wind and solar projects.
The Electrotechnical Skills Partnership (TESP)	Funder	TESP is funding research in Friction Processing technologies at the Nelson Mandela Metropolitan University eNtsa Innovation Hub. TESP is a not-for-profit industry partnership comprising the Electrical Contractors' Association (ECA), Joint Industry Board (JIB), National Electrotechnical Training (NET), SELECT and Unite the Union. The partnership supports electrotechnical employers to develop and drive the industry's skills agenda.
UK Climate Investments LLP (UKCI)	Investor	UK Climate Investments LLP (UKCI) has invested in the Revego Fund with Investec Bank Limited, jointly committing R1 billion, in equal proportions, alongside other investors. The Revego Fund is a private equity fund structured as an en commandite partnership focusing on the electricity sector in sub-Saharan Africa.
UK PACT (Partnering for Accelerated Climate Transitions)	Partner	UK PACT has partnered with South Africa to support action on just transition pathways and a low-carbon economic recovery. Priority areas of focus for UK PACT in South Africa are aligned with key national priorities in the just energy transition, renewable energy, energy efficiency, sustainable transport, and sustainable finance. The first round of funding has launched.
UK-South Africa Tech Hub	Partner	Founded in 2019, the UK-South Africa Tech Hub forms part of the International Tech Hub network delivered by the UK's Department for Digital, Culture, Media & Sport, under a UK government initiative designed to promote digital inclusion and the inclusive growth of the digital ecosystems in partner countries.

Source: *authors*

3.2.3 INSTITUTIONS

This section focuses on the rules, norms and practices that support or hinder emerging technology development. It starts with policy and national narratives before moving to focused discussions on incentives and support systems, regulation (including risks, harm and security issues) and funding for emerging technology.

POLICY NARRATIVES

This review has identified that South Africa's government has focused significant attention on a particular set of emerging technologies – those related to the 4IR. The South African government cemented its efforts around the uptake of the 4IR in 2019, appointing a Presidential Commission on the Fourth Industrial Revolution (PC4IR). The 30-member commission brought together experts across different sectors of society to assist the government in taking advantage of the opportunities presented by the digital industrial revolution. Chaired by the country's President, the commission identified priorities, strategies, and action plans to position South Africa as a competitive global player in 4IR. The PC4IR was tasked with working within four primary workstreams to focus on themes of critical importance. These are: integration; programme management and communications; socio-economic impact (an umbrella term referring to science, technology and innovation, infrastructure and resources, human capital and the future of work, capital markets and financing, commercialisation, and industrialisation); and policy and legal. Furthermore, the PC4IR has targeted several sectors: automotive; clothing and textiles; material and fabrication; agro-processing; forestry and timber; plastics; and chemicals. The PC4IR report was published in 2020 (gazetted September 2020) with eight areas of recommendations:

1. Invest in human capital
2. Establish an artificial intelligence (AI) institute
3. Establish a platform for advanced manufacturing
4. Secure and avail data to enable innovation
5. Incentivise future industries, platforms and applications of 4IR technologies
6. Build 4IR infrastructure
7. Review and amend (or create) of policy and legislation
8. Establish a 4IR Strategic Implementation Coordination Council

It is noticeable that it has focused deliberate attention on two core emerging technology areas: artificial intelligence and advanced manufacturing.

The Department of Communications and Digital Technologies has been tasked with exploring support systems and incentives for all sectors and industries and implementing the PC4IR report recommendations. However, we also found during our desk review that several line ministries have started to engage with digital and 4IR technologies notably:

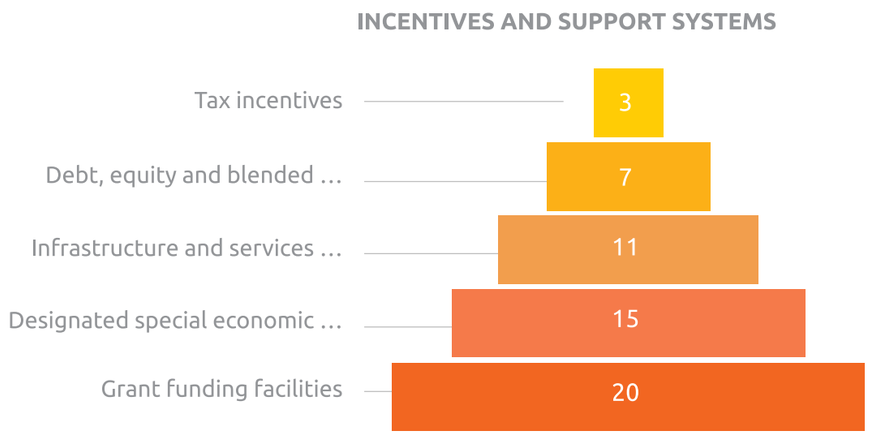
- The Department of Health set out a National Digital Health Strategy (2019-2024) with several priorities. These are: the development of an electronic patient management system; the digitisation of health business systems to ultimately improve quality and efficiency at an institutional level; the training and development of digital health workers; scaling up mobile health (mHealth) initiatives for community-based interventions; and creating an integrated architecture and platform to develop health sector information management, ensuring interoperability and linking existing patient information.
- The Department of Economic Development and Tourism (DEDAT) launched a Dash-Tech programme in the Western Cape that aims to further build on the South African start-up culture to support a technology-drive ecosystem, creating a sustainable environment for job creation and economic growth in a digital economy.

- The Department of Home Affairs (DHA) has taken a centre-lead approach in embracing the 4IR and a digital strategy (White Paper on Home Affairs, 2019). With this, the department has transitioned to online applications, becoming more accessible and therefore launched in malls and at banks. Furthermore, the DHA has initiated mandatory training for staff, in the areas of technological adaptation. Since 2012, with the integration of the biometrics live capture system, the department has welcomed technologies and innovation and is optimistic about having a more cost-efficient administration system and delivering accessible services (White Paper on Home Affairs, 2022).
- The Department of Arts and Culture (DAC) is committed to embracing the 4IR and emerging technologies. For innovation and digitisation in books, audio-visual, video game and music sectors, the DAC will provide grants. It will also support institutions that experiment, focus on research and development, and drive networking in digital entrepreneurship in the arts and culture industries. The department is also open to supporting creative entrepreneurial efforts with the development of emerging digital markets, implementing electronic payments, and simplifying processes related to both digital production and digital distribution (Revised White Paper on Arts, Culture and Heritage, 2017)

INCENTIVES AND SUPPORT SYSTEMS

The South African government has implemented various incentives and support systems for firms through government departments, bodies, and agencies. These include financing and grant funding facilities, tax incentives, and access to infrastructure and services. Several of these are also aimed exclusively at small medium and micro enterprises, reflecting their strategic significance to South Africa's growth and development pathway. For example, the Small Enterprise Development Agency (SEDA) supports 72 sector-specific incubators for SMMEs to facilitate growth. Grant and funding facilities made available are often complemented with business advice, mentoring, skills development and training. Summaries of these incentives and support systems can be found in Annex 3 and an overview is given in Figure 2.

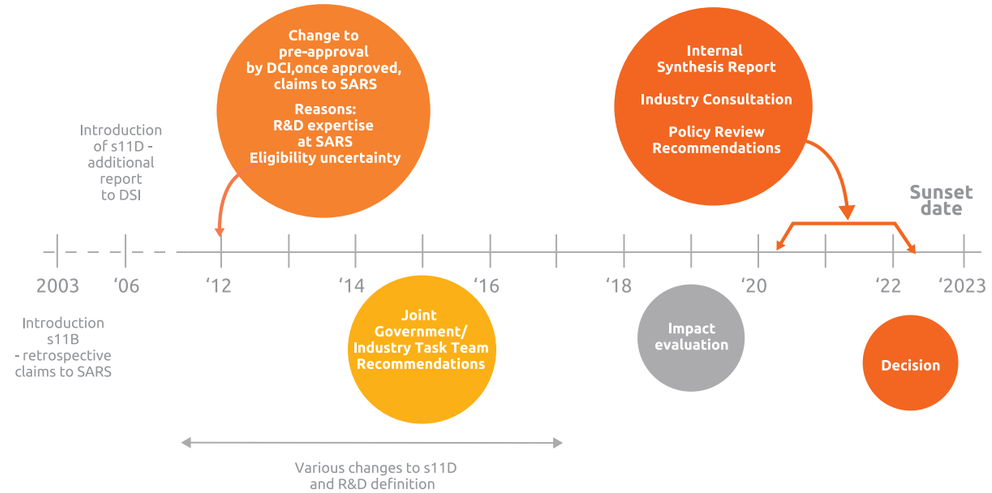
Figure 2: *Emerging technology incentives and support systems available in South Africa*



Source: *authors*

Three tax incentives were found to exist in South Africa (Annex 3, Table 3.1). The best-known is an R&D Tax Incentive administered jointly by the DSI, South African Revenue Service and National Treasury. Acknowledging that science and technology research and developments (R&D) are critical to the country's economic growth and that private sector companies make a weighty contribution to enhanced productivity and innovation in South Africa, the incentive provides support and reduces R&D costs. The incentive was initially implemented in 2006, under Section 11D of the Income Tax Act, 1962, and has since continued to evolve. Figure 3 provides a timeline from the discussion document: Reviewing the design, implementation and impact of South Africa's Research and Development Tax Incentive (National Treasury/ DSI, 2021) that illustrates the changes and evolution of the tax incentive.

Figure 3: *R&D tax incentive timeline*



Source: *National Treasury/DSI, 2021, page 4.*

Any business can claim the incentive, irrespective of the sector it operates within and the size of the organisation. However, it must go through an approval process with the DSI. Once successful, the business may receive 14c back on every South African Rand spent on R&D. The tax incentive is volume-based, implying that the allowance/incentive is dependent on the volume of R&D conducted. Therefore, approved businesses may qualify for up to a 150% tax deduction on eligible R&D activities.

The other two tax incentives are not specific to R&D and emerging technologies but provide incentives to businesses that could help those focusing on emerging technology development or deployment. Specifically, the 12R special economic zone (SEZ) tax incentive (providing reduced tax rates for those operating in an SEZ) and 12L tax allowance for those developing green- and brown-field sites using energy-efficient technologies. Like this is S12B(h) of the Income Tax Act which provides a rebate on purchasing equipment for the production of renewable energies.

Other incentives available include debt, equity and blended finance facilities (Annex 3, Table 3.2). Again, most of these are not specific to emerging technologies with the exception of TIA's sector funding which is focused partly on emerging technology sectors including ICT and advanced manufacturing.

Infrastructure and support services available are provided in a range of areas, generally in entrepreneurship and business development (Annex 3, Table 3.3). The Enterprise Supplier Development (ESD) programme incentivises companies that offer training and development to small supply chain and ESD partners and participants. Large companies ought to spend approximately 3% of their annual profits on such training and development. The programme is one of the country's largest funding drivers for innovation incubators and hubs allowing for R12 billion in capital to be generated for empowerment initiatives (OC&C & Google, 2018).

As noted above, several interviewees emphasised government's National Electronic Media Institute of South Africa (NEMISA), labelling it a significant institution responsible for the development and promotion of emerging technologies in the country. Interviewee 5 stated that NEMISA provides incentives for emerging technology adoption and offers training to intermediaries in several communities, further making specific funding allocations to institutions, such as universities, where there is a focus on digital transformation skills development. The interviewee also highlighted that many universities focus on skills development in local communities which is an incentive to local government. Citizens receive free training in areas of emerging technologies to equip them with new skills and knowledge that can be further applied in local communities. Many universities in South Africa provide incubator, makerspace, fabrication lab space to students and sometimes to outside entrepreneurs. For example, Interviewee 7 highlighted several ongoing projects at the University of Pretoria, funded by the TIA, DSI and other public and private organisations. These projects include several incubators where students are able to receive training and seed funding to develop technologies further.

The CSIR have specific services and support available focusing on a number of the emerging technologies identified in Section 3.2.1 including biomanufacturing and biorefinery technologies, clean tech, nanotech and photonics. This support includes the provision of R&D and testing facilities as well as support to commercialise new technologies.

South Africa has invested in special economic zones to promote the development of businesses and external investment. Several of these (see Annex 3, Table 3.4) are focused on assisting companies working in the following emerging technology areas: green tech (Atlantis SEZ); next-generation farming (Coega IDZ and Dube Agrizone) and next-gen medicine/ medical manufacturing (Gauteng Medical Manufacturing Cluster).

The largest area of support and incentives for emerging technology research, development and deployment that we have identified through the desk review relates to grants (Annex 3, Table 3.5). None of these however are specifically focused on emerging technologies per se but are general grant funding opportunities for business development, often with a sectoral focus.

REGULATION, RISKS, HARM AND SECURITY

With regards to regulation – a key area where most academic studies highlight that businesses suffer challenges to promote and introduce the use of new technologies – a 2020 report released by the National Planning Commission (NPC, 2020) acknowledged that much work needs regulatory efforts, especially in respect of digital technologies. The NPC recommended that an overarching policy or regulatory framework should be implemented for the use of 4IR technologies in their entirety rather than individual policies for each new technology. The NPC also recognises the need for an 'integrated infrastructure plan' so that addresses the basic building blocks relating to light, power, water, roads/ transportation. Nearly a third of interviewees noted the importance of what they termed 'skeleton technologies', 'backbone technologies' or basic infrastructure needed to support the development of emerging technologies. Some incorporated human resources and skills within this grouping and others separated it out. This is discussed in more depth in Section 3.2.4.

To support the development of technologies and innovation, South Africa has the following legislation relating to intellectual property and protections:

1. Intellectual Property Rights from Publicly Financed Research and Development Act 51 of 2008
2. National Environmental Management: Biodiversity Act 10 of 2004
3. Patents Act 57 of 1978
4. Merchandise Marks Act 17 of 1941
5. Copyright Act 98 of 1978 (and Copyright Amendment Act, 2018)
6. Designs Act 195 of 1993
7. Plant Breeders' Rights Act 15 of 1976
8. Trade Marks Act 194 of 1993

The first of these specifically focuses on clarifying who owns intellectual property that is developed within publicly funded organisations in South Africa. It also mandates the owners of the IP to commercialise and utilise the IP for the benefit of the South African society. More recently the government affected the first phase of an IP policy for South Africa that aims to provide direction across these eight Acts of Parliament. The first phase is focused on ensuring South Africa's IP regime is fit for purpose against international standards and is predominately focused on the area of medicines and health. Phase II will look at copyright and other areas.

In addition, while there was no major mention by government agency interviewees or the private sector of internal policies that support and incentivise innovation in emerging technologies, there was recognition by academic community interviewees of policies, standards and regulations within universities and research institutes that dictate how emerging technology R&D and commercialisation takes place. Key among these and most commented on was organisational level IP rules. A key focus of interviewees was the need for clear, consistent and simple regulations and policies. Two quotes exemplify the comments received:

"For instance, as an example, given the issue of blockchain with respect to special cryptocurrencies, we don't have a clear legislation... " and "So the application of genome editing within the agricultural field should have been so simple and quick. But we're still fighting about the regulations. So, the regulations are definitely one of them." (Interview 11)

"For example, SA did develop an EV about 14 years ago, but policies were not in place to support the production of it and the project died" (Interview 14)

With regards to risk, there are two parts to this discussion that should be mentioned. The first is the risk appetite of investors and entrepreneurs. Most interviewees were of the opinion that the risk appetite in South Africa was low but that only those who had an appetite for risk would invest in these technologies, given the uncertainty of their futures. However, also noted in the desk review (and interviews) is the lack of strong and reliable infrastructure and corruption.

The second area of risk relates to the risks and harms from emerging technologies. South Africa has done most here in relation to technologies that are digitally focused. For example, the Cybercrimes Act 19 of 2020 was enacted with several aims intending to create a greater offence around cybercrime, to regulate the jurisdiction in relation to cybercrimes and the powers to investigate it; to impose obligations to report cybercrimes; capacity building; to enter agreements with foreign statements for the detection, mitigation, prevention and other matters related to cybercrime. To ensure data protection, the Protection of Personal Information Act (POPIA) was implemented. Commenced on 1 July 2021, the Act seeks to protect citizens from having their private information accessed, used, and shared without consent. It is also focused on limiting fraudulent activities, identity theft and general protection of information.

There have been some attempts to review the risks and harms to the public of these emerging technologies in South Africa. For example, a 2019 working paper (Goga and Paelo, 2019) reviewed the opportunities and barriers for e-commerce in South Africa and recommended a unified strategy. They present the UK's Digital Competition Expert Panel that ran from 2018 to 2019 as an example of how to review risks and regulatory issues.

We provide a detailed overview of the risks of emerging technologies to jobs, the planet, human health, and increasing inequality in Annex 6 along with the specific risks relating to the top four emerging technologies. These are summarised in Table 9 below and were identified through the desk review. It should be noted that those listed here are all negative risks, however, the PC4IR noted that the risks can be mitigated and not embracing 4IR technologies (as one element of emerging technologies) poses the risk of South Africa losing its economic competitiveness. One interviewee on the PC4IR commission noted that the issue of 4IR technology as a risk to jobs was one of the major issues discussed during the Commission's activities

Table 9: Risks of emerging technologies

RISK TYPE	SUMMARY
Jobs	Puts traditional jobs at risk Exacerbates the skills mismatch existing in the country Use of 4IR in other countries results in the movement of industry to other countries resulting in local job losses
Planet	Plundering of scarce resources with knock-on effects for local communities where there is inadequate regulation Energy use of new 4IR technologies is significant and detrimental as this comes from fossil fuels
Human health	Serious illness is possible from the heavy metals and compounds associated with e-waste in unregulated landfills New workplace health, safety and environment hazards created from new technology development e.g. additive manufacturing Various psychological and physical implications of the 'dark side' of digital technologies related to issues such as cyberstalking and online fraud
Increasing inequality	Existing power dynamics and inequalities can be exacerbated and strengthened by emerging technologies if these technologies are not made affordable and accessible to the poorest and marginalised in society

Source: authors (based on literature in Annex 6)

FUNDING

Interviewees noted funding as a key enabler or barrier to the development of emerging technologies in South Africa. In the recently published South African National Survey of Research and Experimental Development 2019/2020 (see Table 10), government funding accounted for 56.3% of national research and development funding while the business sector contributed 27.1% (CeSTII, 2021). Total national expenditure on research and development in 2019/2020 was R36.784 billion, a 5% decrease from the R38.725 billion reported in 2018/2019.

Table 10: Funding for research and development by source (2010/11 to 2018/2020)

YEAR	TOTAL FUNDS	GOVERNMENT	BUSINESS	OTHER SOUTH AFRICAN SOURCES**	FOREIGN SOURCES
	R'000	R'000	R'000	R'000	R'000
2010/11	20 253 805	9 018 874	8128246	661 67 6	2 445 009
2011/12	22 209192	9 56 1917	8 663 105	653 674	3 330 496
2012/13	23 871219	10 831 893	9152042	770 300	3116 984
2013/14	25 660 573	11 007 083	10 615 902	722 361	3 315 227
2014/15	29 344 977	12 873 458	11 981974	923 530	3 566 015
2015/16	32 336 679	14 425 992	12 578 499	1122 328	4 209 861
2016/17	35692973	16427596	14 045 892	1047980	4171507
2017/18	38 724 590	18 082 182	16 066 846	638 858	3 936 705
2018/19	36 783 968	17 475 173	14 534 123	775 938	3 998 734
2019/20	34 484 862	19 416 933	9 358 770	1046 861	4 662 299

**Includes science council and universi own funds. **Includes funds from higher education institutions, not-for-profit organisations and individual donations disbursed to all sectors.*

Source: Reproduced from CeSTII (2021, p. 12)

According to the latest Partech Partners Africa Tech Venture Capital report (Assou et al., 2022), in 2021 South Africa attracted US$832 million of equity funding in 132 deals. FinTech dominated in terms of resource allocation, followed by Health Tech, enterprise (early stage), and EdTech. Linking finance flows to private actors or specific technologies is, however, challenging with many firms only partially disclosing funding (often in press releases) or keeping details confidential.

There is relatively better transparency with government funding and development agencies. For example, the state-owned Industrial Development Corporation (IDC), whose sectoral remit includes agro-processing and agriculture, automotive and transport equipment, and new industries, publishes quarterly disclosures of IDC funded business partners (e.g., IDC, 2021). The IDC plays a significant role in funding industry and project development in key sectors aligned to the National Development Plan. In 2021, it established a R1 billion fund in partnership with the Department of Agriculture, Land Reform and Rural Development to support agri-industrial development (IDC, 2021), while reporting a R336 million investment in clothing and textiles competitiveness and R10.6 million in agro-processing. A developing list of partially disclosed individual transactions in emerging technology clusters available in the public domain is included in Annex 4. Specifically, the desk review identified 20 partially disclosed individual transactions which included funding for start-ups but also for financing established technology/ companies. It included funding for trials and prototyping as well as scaling funding. In some cases, it also included funding for infrastructure.

This is interesting given that the findings from interviews confirm the availability of funding but that there is insufficient funding at the commercialisation stage. Interviewee 16 noted:

"And I think that helps (referring to funding R&D). On the other hand, we found that the difficulties for us is when you get to commercialising this technology. The support seems to be much less. And we actually end up self-funding what we're doing currently"

Interviewee 16 highlighted the importance of funding the whole value chain of technology development. He added that lack of funding at commercialisation stage for example, leads to the development of technology in the country but implementation elsewhere. Interviewee 14 gave an example of this with desalination, which he said is a technology developed in South Africa but adopted by Israel companies who are profiting from it in other countries. This leads to a missed opportunity in solving South Africa's own socio-economic challenges with our own technologies.

3.2.4 CHALLENGES AND OPPORTUNITIES

For emerging technologies in newer industries, such as drones, AI, and gene editing, regulation has been cited as a key factor impeding both the advancement of technologies and the entry of new actors (Dhai et al., 2020; Ntshavheni, 2021; Schoeman et al., 2017; NEPAD Agency, 2018a). For example, the use of drones in precision agriculture in South Africa has been impacted by both regulation costs and relatively onerous requirements compared to other countries (NEPAD Agency, 2018a). These newer industries also face challenges related to education for both employees, such as in the instance of AI (Schoeman et al., 2017) and additive manufacturing (Alabi et al., 2020), and consumers, such as in the application of 3D printing for housing settlements (ASSAf, 2021). Emerging AI technologies also present unique challenges pertaining to valuation, asset depreciation and intellectual property (Schoeman et al., 2017). Many of these challenges have already been introduced above. We provide a high-level overview of the key challenges and opportunities facing emerging technology in South Africa. These are augmented by additional issues raised during the interviews or identified during desk review and outlined in Table 11. Not included in Table 11, because it spans all of the areas outlined under challenges, is the broad issue of 'barriers to entry' which are higher for some technologies than others. An example noted during the stakeholder validation workshop being the difference between innovating in the biotechnology space as opposed to the digital technology (mobile apps) space.

Table 11: *Challenges and opportunities facing emerging technologies in South Africa*

	CHALLENGES	OPPORTUNITIES
TECHNOLOGY AND KNOWLEDGE	• Debate around the ability of South Africa to develop its own technologies and the relative merits of taking technology from elsewhere and contextualising it. • Lack of skills especially on the user end i.e., simple digital skills and awareness. • Infrastructure issues and access to skeleton or backbone technologies. Relatedly, the importance of general purpose technologies such as electricity. • Incentive structure in universities and brain drain limit the levels of innovation (and commercialisation of) emerging technologies. • Still some deficiencies in the pipeline for researchers and staff for technology development companies.	• Training and knowledge around emerging technology are increasing e.g., the school syllabus will include coding and robotics from 2023 and SETAs are increasingly providing training on 4IR technologies. • Universities have begun taking emerging technologies into account and including teaching into their curriculums, both formal and CPD/ short learning programmes. • Likewise, companies are realising the importance of training and upskilling of staff and have introduced training programmes. • The opportunities availed from coupling and convergence of technologies i.e., combinations of technology today.
ACTORS AND NETWORKS	• Despite some evidence of partnerships and collaboration, gaps remain especially creating a 'valley of death' between the development and commercialisation stages of these technologies.	• Government attention is currently focused on 4IR, one significant part of the emerging technologies list. • Role of SMEs as well as large firms and multinationals in this space. • Evidence of partnerships and collaboration, some involving the private sector. South Africa is involved in important regional initiatives on emerging technologies.
INSTITUTIONS	• Deindustrialisation and decay of physical infrastructure creates lack of risk appetite especially for foreign investors. • While policies and regulations exist, they are often cumbersome and unclear creating confusion and reducing the interest of actors to become involved. • Funding and incentives appear to be available but are not often dedicated to the emerging technologies that are the focus of attention in South Africa; many are focused on entrepreneurship and business development generally.	• Government policy to promote emerging technologies is notably mentioned in the White Paper on STI, 2019. • Universities increasingly have policies and programmes in place to promote innovation and entrepreneurship. • The recent decision to develop an IP policy for South Africa aims to make IP legislation more facilitatory and in line with international legislation.

Source: *authors*

A key issue that has not been adequately discussed in previous sections but was raised by interviewees and requires special attention relates to the degree to which South Africa should be developing technologies. This would be instead of importing them and contextualising these to the needs of South Africa. One interviewee put this very strongly:

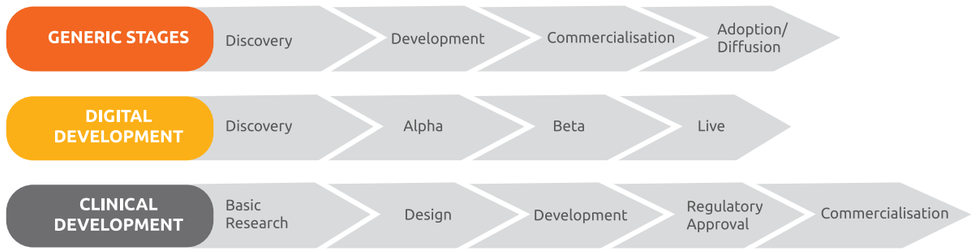
"…I don't think we should even try to second guess what the rest of the world is doing… let's be honest, we shouldn't. We should quite happily just accept frontier technology from India, China, the US, Europe, etcetera. For us to reinvent wheels it would be putting our energy in the wrong place, so we should not be reinventing. …we should be focusing our energy on how to put new technology to work in a South African and an African context. That is where our focus should best be …that can be done in partnership with the global tech providers, because we can be a good proving ground for applications of emerging technology."

A key argument related to this was the pipeline issue (not having enough technical people in new emerging technologies yet versus the more established emerging technologies). The other related argument used was that South Africa is unable to commercialise technology sufficiently because of a low-risk appetite and lack of funding.

3.3 EMERGING TECHNOLOGY ALONG THE INNOVATION LIFECYCLE IN SOUTH AFRICA

While emerging technologies are defined as novel and having potential to create new economic sectors or disrupt existing ones, they are not always defined as emerging because they are found at the start of the technology innovation lifecycle. Emerging technology does not only refer to those emerging at the adoption/ diffusion stage of the lifecycle i.e., as emerging in use. In fact, technologies are defined by the literature and by the interviewees as 'emerging' across all stages of the innovation lifecycle (see Figure 4).

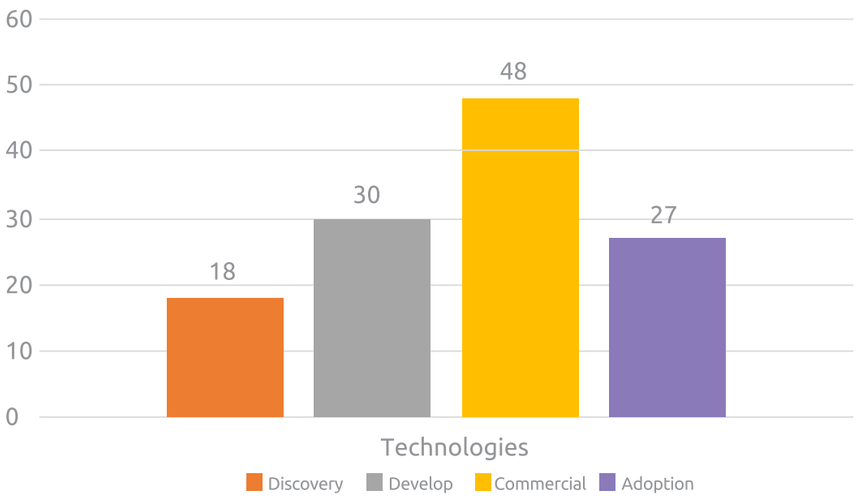
Figure 4: *Different innovation lifecycle models*



Source: *Authors building on Nwaka and Ridley (2003) and https://www.gov.uk/service-manual/agile-delivery*

Most of the emerging technologies identified in the desk review can be classified as emerging at the later stages of technological development (commercialisation and adoption stages) as opposed to the discovery and development stages (see Figure 5).

Figure 5: *Figure 5: Emerging technologies in South Africa at different stages of the life cycle*

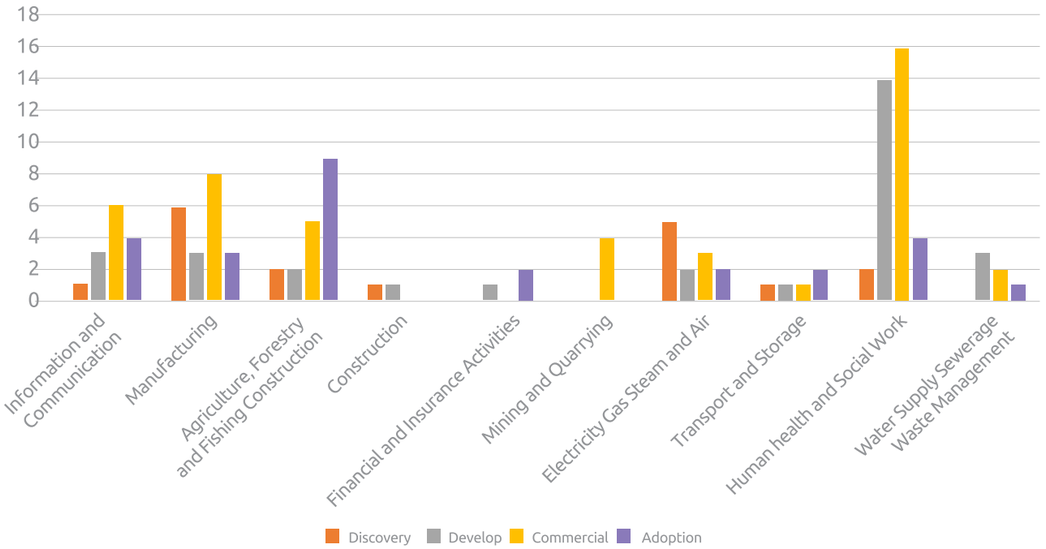


Source: *authors*

When reviewed at a sectoral level we find that some sectors have more discovery and development work than others. This is illustrated in Figure 6 where the electricity, gas, steam and air sector have more technologies emerging at the discovery stage. In several sectors we were unable to identify any discovery work on-going e.g., finance and insurance sector and mining and quarrying. This is at odds perhaps with the findings from the interviews which identified financial services and mining as key areas where emerging technologies were being promoted. However, it is assumed that this is because there is more awareness of the technologies when they are at commercialisation and adoption stage. This may also link to an unconscious bias in our desk review (notably our systematic literature review) that means technologies are not written about as much unless they are at a certain level of development.

Annex 5 provides a breakdown of all the technologies identified at the different stages of development. Here we would like to provide two use cases to illustrate the current status of technologies at the commercialisation stage.

Figure 6: *Emerging technologies by stage and sector of development*



Source: *Authors*

CASE STUDY 1: PRECISION AGRICULTURE IN SOUTH AFRICA

South Africa has a diversified, market-orientated agriculture sector characterised by low concentration with many small, medium and micro enterprises participating (Statistics South Africa, 2022a). While the sector's contribution to GDP continues to hover around 2.1% (Statistics South Africa, 2022b), its continued development is a key strategic objective of the South African government to promote rural economic development, ensure household food security, and address unemployment. Overseen by the Department of Agriculture, Land Reform, and Rural Development. Government support for innovation in the sector centres on the Agricultural Research Council (ARC) as the main agricultural research institution in South Africa, the Technology Innovation Agency Agri Business Unit, the Council for Scientific and Industrial Research Advanced Agriculture and Food Cluster, and the Industrial Development Corporation (IDC) Agro-processing and Agriculture Strategic Business Unit. Businesses also have access to sector-specific incentives and support systems, including the IDC's Agri-Industrial Fund and the DTIC's Agro-Processing Support Scheme. The South African Revenue Service also exempts the acquisition of certain farm inputs from VAT, including animal feed, fertiliser and plants and seeds used for cultivation.

Private sector actors have also mobilised to advance the adoption and diffusion of new technologies in the sector, establishing PACSys (Pty) Ltd (n.d) in 2016 as a technology company focussing on precision agriculture. In 2019, a joint venture between PACSys and DC Geomatics was approved as the first commercial licensed drone spraying operator in the country. Another high-profile start-up utilising emerging technologies is Aerobotics (Pty) Ltd (n.d). Founded in 2014, the company has raised $27 million, with the latest round of $17m announced in January 2021. Aerobotics product offering combines AI tools, drone imagery and mobile application technologies to address several key farming challenges.
The company's customer footprint already extends to 18 countries. However, although precision agriculture appears well-positioned for adoption and diffusion, there are concerns about onerous regulations for drone operators, suggesting that opportunities may be limited to larger firms with the capacity and financial resources to meet regulatory requirements.

CASE STUDY 2: 3D PRINTING IN SOUTH AFRICA

The African Union Development Agency-NEPAD has identified 3D printing as one of ten priority emerging technologies relevant to Africa's socio-economic development. First introduced in 1991, by 2018 there were an estimated 5700 machines, with the industry growing exponentially from 2010 onwards (RAPADSA, n.d). Industry ownership now exceeds universities and public research institutions (RAPADSA, n.d). Encouragingly, most universities have 3D printing facilities, while several have dedicated research programmes. North-West University is leading research into 3D bioprinting for bio fabrication, while the Central University of Technology's Centre for Rapid Prototyping and Manufacturing has worked extensively with the medical industry. As Alabi et al. (2020) emphasise, adequate funding is a significant factor in promoting education and research in additive manufacturing.

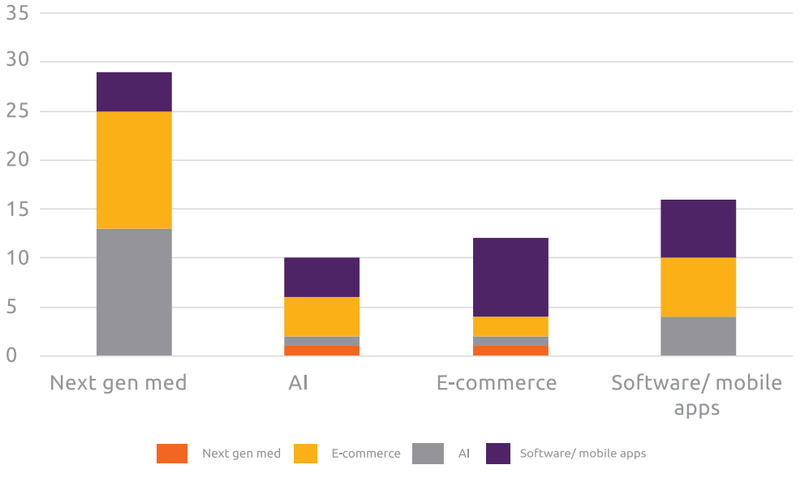
Several notable collaborations between industry and public institutions have underlined the importance of state actors in technology development in South Africa. In 2017, the Platforum partnership between the Central University of Technology, North-West University, Vaal University of Technology, and Lonmin announced the successful prototyping of 3D printed platinum jewellery. Another industry first emerged from the South African Aeroswift project, a collaboration between aviation manufacturing company Aerosud and the Council for Scientific and Industrial Research. Launched in 2011, the Aeroswift project has successfully developed the world's largest 3D printer and manufactured a metal framework for drones. Expertise from the Aeroswift project has also led to start-up Aditiv Solutions creating its own machine, which was prototyped in 2021.

Reflecting the breadth of potential applications, 3D concrete printing is currently being explored as a housing solution, spearheaded by the Department of Human Settlements in conjunction with industry and university actors (ASSAf, 2021). The Department of Water and Sanitation (DWS) is investigating ways of applying the technology for water and sanitation solutions (ASSAf, 2021). Existing government support coupled with industry adoption suggests that South Africa is well-positioned to leverage existing knowledge and expertise to develop 3D printing applications further.

3.3.1 TIERING OF TECHNOLOGIES

It is possible to see two tiers of emerging technologies. The first tier is what might be termed new emerging technologies. Based on the list of the top 10 emerging technologies identified across the public and private sectors (Table 2, Section 3.2.1), we can identify the two top new emerging technologies: artificial intelligence and next generation health. These have the highest numbers of projects identified across both the public and private sector and have less activity at the adoption stage of the lifecycle relative to other stages (see Figure 7); hence the framing as 'new emerging technologies'.

Figure 7: *Top new and waning emerging technologies by projects at lifecycle stages*



By comparison, e-commerce and software/ mobile application technologies, while not having as many projects across the innovation lifecycle were found to have the highest number in the adoption phase of the lifecyle. As such we suggest referring to these as 'waning emerging technologies'. These technologies can be seen as becoming what are known as 'general purpose technologies' or core technologies that have uses across multiple sectors and form a critical base technology for other technologies to build onto.

It is noted that the four top emerging technologies identified in 3.2.1 (next generation health, AI, e-commerce and software/ mobile applications) appear to suffer from bottlenecks at different places along the production lifecycle. Figure 8 below provides a depiction of these.

Next generation health appears to suffer from potentially two bottlenecks: at discovery stage and in moving technologies into widespread adoption. The reasons for this have been determined as related to the difficulty of establishing the value of a product in the early stages and therefore issues with attracting funding for early stage work. In addition, the standards and regulations are high across the innovation lifecycle for next generation health. At adoption stage regulation is seen to play a key role as is the complexity of actors and healthcare systems. Annex 7 expands on these.

Figure 8: *Bottlenecks across the lifecycle for the four top emerging technologies*

Source: *authors. Notes: AI – Artificial Intelligence; E-C – E-commerce; MApps – Mobile applications; NGM – New Generation Health*

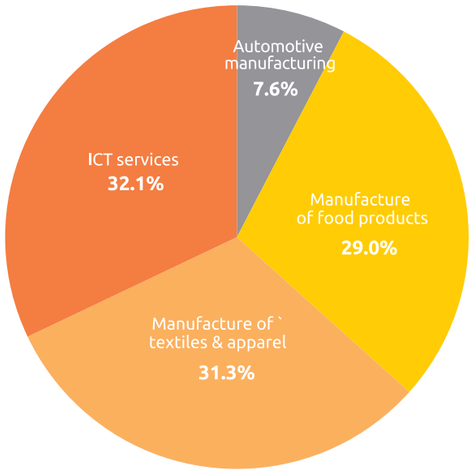
This is particularly pertinent for the waning emerging technologies of mobile applications/ software and e-commerce. That they are waning i.e., becoming accepted and normalised, should not mean that they do not receive funding and support to continue technological innovation. This is particularly necessary given their potential to be seen as general purpose technologies of the future. However, identifying the issues faced by these technologies at particular stages of the lifecycle has proven difficult. Regulation has been identified as a key barrier to the development and especially adoption of these technologies (although the fact that these technologies are the most diffused suggests that it is possible to operate in the current regulatory environment and not only because these technologies have been a focus of attention by industry for some time). A key barrier identified for e-commerce is infrastructure. This also impacts the other technologies, most notably the difficulty of ensuring adequate and reliable access to electricity in South Africa.

3.4 ZOOMING IN TO EMERGING TECHNOLOGY USE IN SOUTH AFRICA

This section employs recent survey data on frontier technology adoption in South Africa being collected as part of a broader project between the UJ-TRCTI and UNCTAD. The data provides an opportunity to understand how several of the emerging technologies listed in Table 2 (Section 3.2.1) are being used in South Africa. Our analysis is based on 262 formally registered firms in the service and manufacturing sectors across the nine provinces in South Africa. They were asked in a survey conducted in late 2021 and early 2022 about their current use of a group of frontier technologies, the capabilities they must have to use these technologies as well as the barriers they face in using them. The frontier technologies examined were e-commerce; social media; mobile banking/ money; cloud computing; big data; AI; 3D Printing; IoT; industrial robots; collaborative robots; VR/AR.

Figure 9 provides an overview of these firms in terms of sector focus. As we can see from the figure, around 70% of the firms operate in the manufacturing sector, with the majority (31%) concentrated in the manufacture of textiles and apparel, 29% operate in the manufacture of food and products, and 7.6 % are in automotive manufacturing. Firms in the ICT services represent around 32% of the sample.

Figure 9 *Distribution of firms by sector (in % of the total sample)*



Source: *Frontier technology adoption dataset, authors' calculations. Sample size: 262.*

Table 12 shows thve distribution of the firms by sector and size. The firms are clustered into three groups: micro-firms include firms with less than 10 employees; small firms are firms that have between 10 and 24 employees, medium firms include firms with between 25 and 99 employees, and large firms are firms with more than 100 employees. The majority of the 262 firms are micro firms representing 43.1% of the total sample, followed by small firms representing 33.7%. We also observe that micro, small, and medium-sized companies are primarily concentrated in manufacturing food products, textiles and apparel, and ICT services. In contrast, large firms with more than 100 employees are less concentrated in ICT services and have equal representation in the manufacturing sectors.

Table 12: *Share of firms by sector and firm size (in % of the total sample)*

	MICRO FIRMS	SMALL FIRMS	MEDIUM FIRMS	LARGE FIRMS	TOTAL
Automotive manufacturing	2.3	1.1	1.1	3.1	7.6
Manufacture of food products	14.1	7.6	4.2	3.1	29.0
Manufacture of textiles & apparel	13.8	8.0	6.1	3.4	31.3
ICT services	13.0	11.1	6.1	1.9	32.1
TOTAL	43.1	33.7	11.9	11.3	

Source: *Frontier technology adoption dataset, authors' calculations.*

When we look at these firms and their use of frontier technologies (Table 13), we find very few firms that do not use any of these technologies. Where this is the case it pertains to a small group of micro and small firms. In fact, we find that over 70% of all firms use more than two of the technologies investigated in this study.

Table 13: *Share of firms that used 0, 1, 2 or more than 2 digital technologies by firm size*

	FRONTIER TECHNOLOGIES (IN % OF EACH FIRM SIZE)			
	0	1	2	MORE THAN 2
Micro firms	0.9	7.1	20.4	71.7
Small firms	2.7	5.5	15.1	76.7
Medium firms	0.0	6.5	17.4	76.1
Large firms	0.0	10.0	10.0	80.0

Source: *Frontier technology adoption dataset, authors' calculations.*

ADOPTION OF NEW AND EMERGING TECHNOLOGIES

Figure 10a reports the adoption of new and emerging technologies by sector and highlights that social media is the most used emerging technology across all the sectors, followed by mobile banking/ money. The highest rate of social media adoption is 96% registered in the manufacture of goods and products, and the lowest rate is 85% in the manufacture of textiles and apparel. Cloud computing and e-commerce are also important emerging technologies used across the different sectors. As expected, industrial robots are primarily used in automotive manufacturing, where 30% of the firms adopt this advanced technology compared to 1% in the two other manufacturing sectors. Figure 10b on the right-hand side reports how firms of different sizes adopt the new and emerging technologies. Social media is widely adopted across all size categories and the highest adoption rate of this digital technology ranges from 94.7% for micro firms to 83% for large firms. Mobile banking/ money is the second most adopted digital technology by micro, small and medium-sized firms. For large firms, mobile banking/ money adoption is ranked in third place after cloud computing, that is adopted by 76.7% of the large firms against 63.3% for mobile banking/ money.

Figure 10 *– What are the most adopted digital technologies?*

Fig. 10a *– (in % of each sector)*

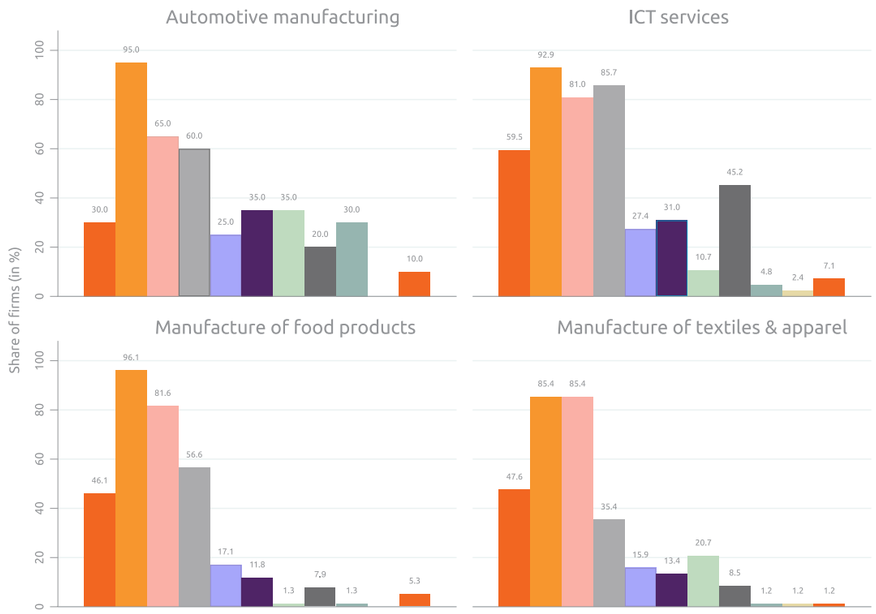
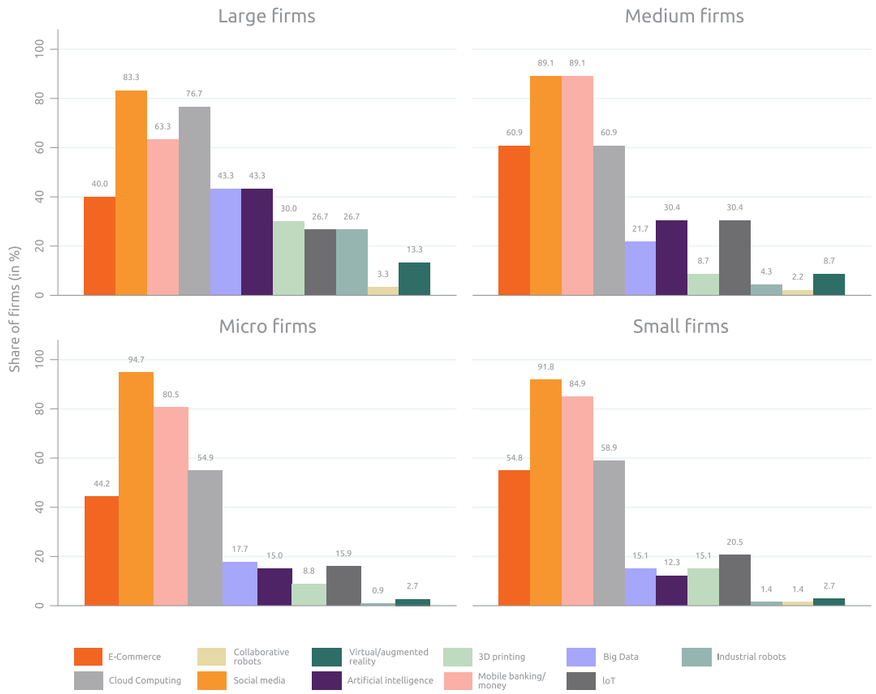


Fig. 10b *– (in % of each firm size)*



Source: *Frontier technology adoption dataset, authors' calculations.*

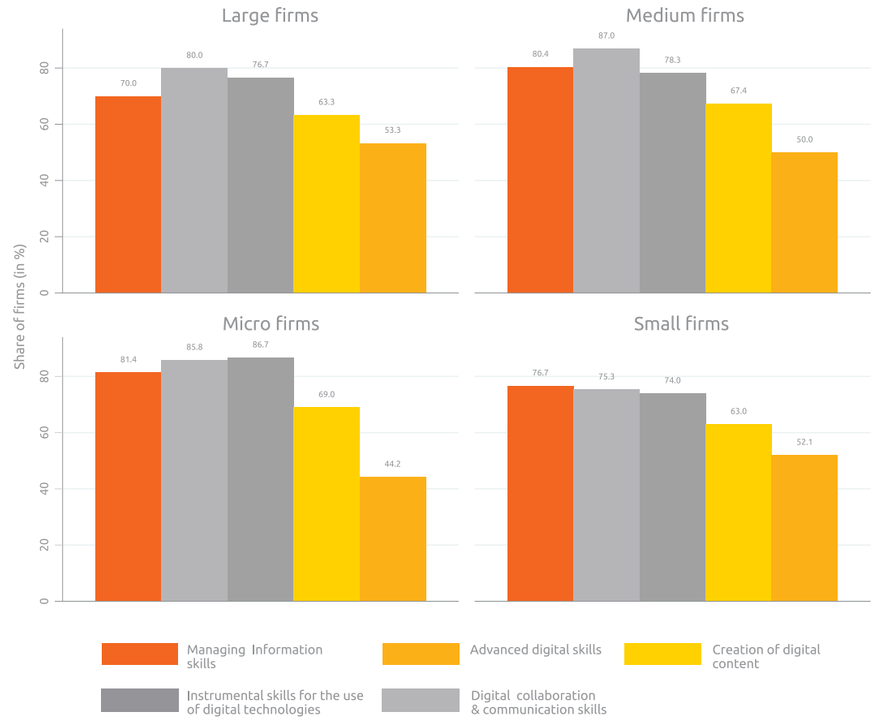
BARRIERS AND OPPORTUNITIES TO TECHNOLOGY ADOPTION

The previous figures show dynamism in the adoption of new and emerging technologies by South African firms. This is borne out in Figure 11 with regard to firms' digital skill capabilities. Here we see that over 70% of firms of all sizes have digital skills inside the firm relating to managing digital information, digital communication and instrumental use of technologies. However, there is a drop-off in confidence that they had more advanced digital skills especially in the small and micro-sized businesses.

The above notwithstanding, there are still barriers to technology adoption. Based on Figures 12a (which illustrates barriers for each sector) and 10b (which illustrates barriers for each firm size), we find these barriers are two-dimensional and combine (i) a shortage in adequate infrastructures (especially high-quality infrastructures) with (ii) a lack of investment, including in digital skills to absorb, imitate and use digital technologies. For example, 36.8% of firms in the manufacture of food products (respectively 32.1% in ICT services) consider the technology infrastructure poor. Another example is the lack of finance: 23.8% of firms in ICT services, 25% of firms in automotive manufacturing, and 26.3% of firms in the manufacture of food products rank this lack as one of the top 3 most significant barriers to digital technology adoption.

Moreover, 45% of firms in automotive manufacturing are strongly attached to traditional ways of doing things even though the digital era is characterised by its disruptive nature, whether in terms of knowledge, skills, means of production, or innovation.

Figure 11: *What digital skills do firms have? (% of firm size)*



Source: *Frontier technology adoption dataset, authors' calculations*

Figure 12 - *What are the most significant barriers to adopting these technologies?*

Figure 12a - *– (in % of each sector)*

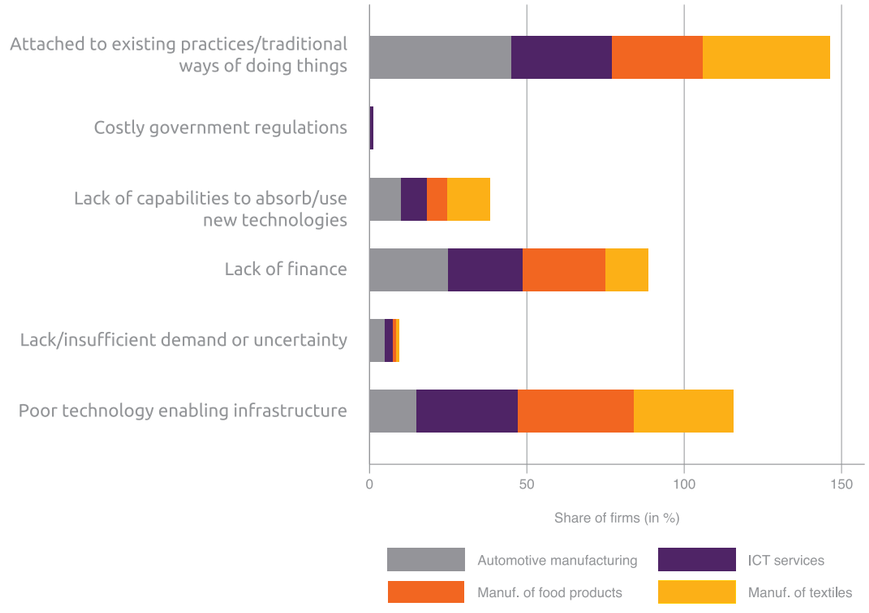
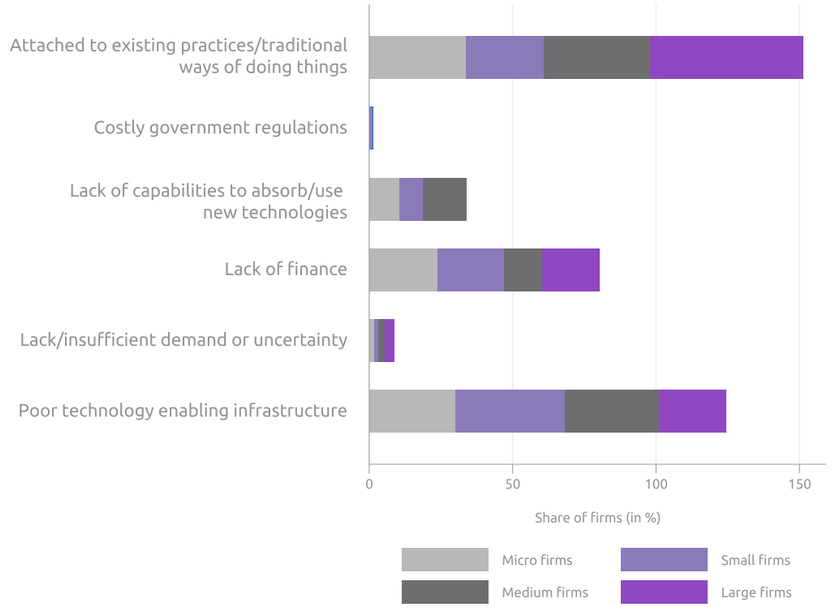


Figure 12b - *(in % of each firm size)*



Source: *Frontier technology adoption dataset, authors' calculations*

4. Summary and recommendations

This report has outlined the findings of a landscape analysis of emerging technologies in South Africa. This final section summarises the findings of the preceding sections before providing some recommendations.

4.1 SUMMARY OF FINDINGS

We revert here to Section 2 and the original research questions that shaped this report.

What is the definition, status and types of technology defined as emerging technology?

This report developed a revised definition of emerging technologies based on that of Rotolo et al. (2015). This takes into account that we found a range of technologies described as 'emerging' and at various stages of the innovation lifecycle. We also found that these technologies are used across multiple sectors although the largest use of emerging technologies was in the sectors of human health and social work as well as agriculture, forestry and fishing.

An overview of these four technologies is provided in Table 14 and in more depth in Annex 7 where we provide a 'deep dive' into these four technologies as well as one that is non-digital and can be non-4IR based. This fifth deep dive is focused on water purification. We have included this because it is important to acknowledge that despite the dominant narrative in South Africa on 4IR type technologies, there are important technologies that are discussed as emerging in South Africa (and make the top 10 list) but which are not always 4IR focused.

Table 14: *outlines a summary of the top four emerging technologies in South Africa*

WANING EMERGING TECHNOLOGIES	NEW EMERGING TECHNOLOGIES
MOBILE APPLICATIONS	**NEXT GENERATION HEALTH**
This technology is wide-ranging in focus covering multiple sectors from finance/ banking to healthcare, agriculture and leisure. Involves the development and use of ICT products on phones. **Policy support:** Mentioned by many line ministries in their strategic plans but no longer a major focus of national policy **Actors:** Very little visibility of research actors in this space but good set of private sector companies. **Stage of development:** Most technologies identified focused at adoption/ diffusion stage. None identified at discovery stage. **Funding:** Little evidence of funding in this area. **Key issue faced:** Increasing recognition of the need for risks, harms and security issues.	This includes the latest diagnostics, vaccines, medicines and treatments (but excludes new materials). **Policy support:** High degree of policy support, mentioned in Department of Health strategic plan as well as PC4IR report and APET. **Actors:** Strong visibility of South African funding agencies, universities and private sector companies. **Stage of development:** Most technologies identified focused at development stage. Few have moved to commercialisation and less to adoption. **Funding:** Significant research funding and a few examples of venture capital funds. **Key issue faced:** Regulation is a significant hurdle but is now the focus of South Africa's IP policy.

WANING EMERGING TECHNOLOGIES	NEW EMERGING TECHNOLOGIES
E-COMMERCE	**ARTIFICIAL INTELLIGENCE**
ICT applications that enable buying and selling of goods and services over the internet. **Policy support:** Received a boost when the 2020 COVID-19 pandemic started but not visible in policy documents. **Actors**: Strong visibility of South African private sector companies in this space. **Stage of development:** Most technologies identified focused at adoption stage. Few at earlier stages. **Funding:** Only a few examples of venture funding found. **Key issue faced:** Digital skills are required by users and not just the technology developers. South Africa has low levels of digital skills in the general population, but recognition and training efforts have started.	This refers to the use of computers to sense, think and learn to conduct tasks. **Policy support:** Extremely high degree of policy support, mentioned in PC4IR report with recommendation for its own Centre and APET. **Actors:** Strong visibility of South African funding agencies, universities and private sector companies. **Stage of development:** Most technologies identified focused at commercialisation and adoption. Few visible in early stages despite significant research programmes in this area. **Funding:** Significant research funding and a few examples of venture capital funds. **Key issue faced:** digital skills competency in South Africa is low as is public understanding of this technology.

Annex 5 highlights that many emerging technologies are being used in combination and the issue of convergence of technologies was mentioned several times by interviewees. Annex 5 also highlights several examples of where projects are developing a product that uses multiple technologies. For example, Nutrileap, a diagnostic to assist clinicians with their patient's diet needs, uses a combination of medical diagnostics, artificial intelligence and a mobile application.

What factors have influenced the growth or lack of growth of emerging technology in South Africa?

The top three factors identified during this analysis are: skills, funding and regulation.

Skills – There was differing opinion on the status of emerging technology skills in South Africa. There was general acceptance that generally the level of digital skills is low (borne out by the latest figures) and that this negatively impacts the uptake and use of new technologies by users and communities. There was a general sense that the education system in South Africa was improving and that while the country was producing graduates, many firms needed to provide additional technology specific training to new employees.

Funding – Despite finding a number of examples of funding of emerging technologies (Annex 4) and incentives and support systems available, many interviewees and the quantitative data highlight funding (lack thereof) as a barrier. This might be because much of that which is available is generic or focused on entrepreneurship and business development as opposed to specifically supporting technology development. IDC, TIA and DSI were key funding organisations named in the innovation field, while NRF was dominant for research. There was a sense during interviews that funding schemes benefited the incumbents more.

Regulation – Despite a range of laws, policies, incentives and standards being available the majority of views expressed by stakeholders involved in this study was that the regulatory environment was often cumbersome and lacked clarity. The recent IP policy and efforts to implement this was identified as a step forward and there are regulations from a risks and harms perspective now in existence for some digital technologies. However, there are often no specific regulations at the individual technology level.

What role do different actors play, particularly government departments in South Africa, regional organisations and UK organisations?

There are five main government actors in the policy space in South Africa that were mentioned by all interviewees: DSI, CSIR, TIA, IDC and NRF. These each have specific mandates and activities although there does appear to be some overlap at times. A diverse range of universities are involved in these technologies with no single university appearing more visible than others. This is because they often appear to focus on different technologies. A range of different private sector firms work in different sectors. An important finding is the use of emerging technology by small and medium-size firms and not just large-scale and multinational firms.

South Africa is involved in four regional initiatives that are specifically focused on emerging technologies: African Biosafety Network of Expertise (ABNE), African Biosciences Initiative (ABI), NANOsciences AFrican NETwork (NANOAFNET) and SmartAfrica. South African organisations are also part of at least 17 different partnerships and collaborations which cover many of the emerging technology areas identified, notably 3D printing, agro-processing, drones and artificial intelligence.

We also identified 10 instances where UK firms or government organisations were involved in supporting emerging technology development, deployment and use. Unfortunately, clear figures for the levels of investment are not available. This is in addition to more established partnerships between the UK government and South Africa e.g., the UK research councils (UKRI) and the NRF.

What policies exist and what is the status of implementation?

South Africa has a mature policy in the area of STI. It recently (2019) updated its White Paper on STI, it has had a Presidential Commission on one particular set of emerging technologies (those related to the 4IR) and it has started to address deficiencies in its IPR legislation starting with the first phase of an IP policy development and implementation.

There have also been some attempts to develop technology specific strategies or roadmaps including those focused on 3D printing (the South African Additive Manufacturing Strategy), the waste to energy roadmap, water research, development and innovation roadmap and hydrogen society roadmap. There appears to be no comparable document for next generation health, although the CSIR have a programme cluster with an internal plan focusing on next generation health. Similarly, the analysis has not found a country level AI strategy or roadmap, although the SmartAfrica initiative is developing a blueprint for AI for the continent.

What are the risks to individual privacy, repression, inequality and exclusion, power dynamics linked to asymmetric access to information, jobs and labour, barriers to market entry?

There is a big academic literature referring to these issues and significant attention in South Africa at a policy level (PC4IR) on these in relation to a particular set of technologies (related to the 4IR). However, we did not find in existence a comprehensive review of risks relating to emerging technologies in South Africa. The focus has been on security issues of new technologies which has led to the enactment of the Cybercrimes Act in 2019 and the Protection of Personal Information Act in 2021. Related to this is some evidence of training in cybersecurity focusing on users of technology. However, while the training of users in digital skills and emerging technologies has been gaining ground, it appears this is mostly focused on addressing a gap in digital skills and not from a risk or harm perspective. There is a broader narrative, especially in the general media, which is mirrored in the academic literature on the implications of, mostly 4IR technologies, on jobs and labour dynamics.

In addition, a further risk area relates to investor and entrepreneur appetite for risk. This was deemed as low during the interviews, limiting the levels of investment and the movement of technologies along the production lifecycle.

The last two overarching questions that were the focus of this landscape analysis (What are the key gaps in emerging technology? What are the opportunities for the UK to strengthen partnerships in each country?) relate to recommendations and are answered in the next section.

4.2 CONCLUSIONS AND RECOMMENDATIONS

In this final section we outline the key conclusions of this landscape analysis and suggest a number of recommendations. The first recommendation would benefit countries beyond South Africa. The remaining recommendations are specifically focused on South Africa.

This landscape analysis identified 20 emerging technologies that are being promoted, developed, deployed or are in use in South Africa. Of these, the top four can be divided between new emerging technologies (artificial intelligence and next generation health) and waning emerging technologies (mobile applications and e-commerce). These waning technologies are not disappearing from view but are becoming accepted and assimilated into processes and becoming a form of general purpose technology. This, together with the fact that the analysis has identified low-tech and high-tech emerging technologies being promoted, developed and used across all stages of the production lifecycle means that a clearer definition of 'emerging technology' is needed.

Recommendation 1: A revised and more nuanced definition of emerging technologies or tiering of emerging technologies would help ensure that the debate on emerging technologies is not dominated by a particular interest area (e.g., 4IR technologies) and that a broad spectrum of technologies receive attention.

The use of roadmaps and strategies are noted as being used to guide the development and diffusion of a number of emerging technologies and sectors utilising emerging technologies. There are, however, no apparent roadmaps or strategic plans to guide the development of the top four emerging technologies identified. This is despite a significant level of activity taking place in these areas and a plethora of actors being involved.

Recommendation 2: UK agencies to hold consultations with relevant South African agencies (notably Department of Science and Innovation, the Council for Scientific and Industrial Research and the Technology Innovation Agency as well as relevant line ministries) on the benefits of developing roadmaps for the top emerging technologies and supporting the production of these.

It is noted that the four top emerging technologies appear to suffer from bottlenecks at different places along the production lifecycle. Figure 13 provides a graphical depiction of these. While there are existing funders and actors involved across these lifecycles, the existing bottlenecks highlight areas where more attention is needed.

Figure 13: *Bottlenecks across the lifecycle for the four top emerging technologies*

Source: *authors. Notes: AI – Artificial Intelligence; E-C – E-commerce; MApps – Mobile applications; NGM – New Generation Health*

This is particularly pertinent for the waning emerging technologies. The fact that they are waning i.e., becoming accepted and normalised should not mean that they do not receive funding and support to continue technological innovation. This is particularly necessary given their potential to be seen as general purpose technologies of the future.

Recommendation 3: UK agencies to work with South African counterparts to showcase the status of these emerging technologies with British firms and organisations to build partnerships to remove the bottlenecks.

There is an increasing focus by the South African government and other actors on policy and regulatory issues relating to emerging technologies. This has been prompted by the country's proactive engagement with the 4IR. However, the country still lags behind others on the continent in terms of digital skills. This has a knock-on effect in industry on attitudes to new technologies (as noted in the survey results presented). Linked to this is the lack of a comprehensive set of strategies and analysis on the risks of these emerging technologies. The UK has significant experience reviewing risks related to emerging technologies and the UK's Digital Competition Expert Panel, has been highlighted as an example that could be relevant for South Africa.

Recommendation 4: UK agencies to work with members of the UK's Digital Competition Expert Panel and others to provide reflections on what has worked and not worked in identifying and addressing emerging technology risks as part of South Africa's on-going efforts in this area.

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ANNEXES

ANNEX 1: Research methodology

The research project took place between January 2022 and April 2022. The research data collection took the form of a desk review, review of secondary survey data and key informant interviews. Data was analysed using thematic analysis and non-parametric statistics as appropriate.

DESK REVIEW

We have conducted a thorough search of various online resources (academic papers and grey literature). The desk review has been conducted in four areas. The first three reviews utilised a combination of grey and academic literature with each focused on a different element of the innovation system: technology and knowledge, actors and networks and institutions. The fourth review consisted of a systemic literature review focused solely on academic literature.

INTERVIEWS

Interviews took place in April 2022 with a mop up in May 2022. All participants were provided with a participant information sheet and only interviewed once informed consent was given.

A single generic interview guide was utilised across all respondents to aid generalisability of results. The generic interview guide highlevel questions were:

1. In your opinion, what is the status of the Emerging Technology industry in South Africa?
   - Prompts: What sectors? Are there dominant technologies? What stage of development are the technologies?
2. Based on this description, how would you define Emerging Technologies?
3. What is the status of training and research on Emerging Technologies in South Africa?
4. Who are the actors that are most visible in the Emerging Technologies space in South Africa?
   - Prompts: When did they get involved? How are they involved? How much money are they investing?
5. What is your understanding of South Africa's involvement in regional (AU, SADC) Emerging Technologies initiatives?
   - Prompts: What regional/ global initiatives are there which South Africa is not taking part in? Any reasons why they aren't involved?
6. What about South Africa's involvement in Global initiatives?
7. Which government departments in South Africa are looking at emerging technology (coordination, implementation, etc)?
8. What policies exist to support emerging technology development and deployment?
   - Prompts: what is the status of implementation?
   - Note: these could be strategies, policy directives, adopted standards such as the OECD AI
9. What incentives or support systems exist for those operating in this field in South Africa?
   - Note: e.g., prizes, preferential taxes, innovation hubs/ parks etc.
10. What rules govern the use of emerging technology and protect citizens against harm in South Africa?
11. What (other) factors have influenced the growth or lack of growth of emerging tech in Africa?

These questions were tailored to refer to government departments, policies, incentives, rules etc. that the respondent has interacted with as part of their efforts to promote one or more specific emerging technologies.

Interviewees where purposively selected based on their knowledge of the sector and to ensure inclusion of a range of different stakeholders. We are unable to provide names of those who have been interviewed but have provided details of their affiliation and the date of their interview.

ACADEMIA	INTERVIEW DATE
University of Johannesburg, Process, Energy & Environment Technology Station (PEETS) and Chemistry Department	11 April 2022
University of Johannesburg Technology Transfer Office (TTO)	11 April 2022
University of Johannesburg INVT	11 April 2022
Computing and Mathematical Sciences at University of Mpumalanga	12 April 2022
Faculty of Informatics and Design - Cape Peninsula University of Technology	13 April 2022
Department of Electrical Engineering - University of Cape Town	19 April 2022
Department of Research and Innovation - University of Pretoria	19 April 2022
Tshwane University of Technology	20 April 2022
Digital Business - Wits Business School	25 April 2022
University of Johannesburg/ Presidential Commission on the 4IR UK-based Aparito have	20 April 2022

GOVERNMENT	INTERVIEW DATE
Biosafety South Africa	05 April 2022
Department of Communications and Digital Technologies	11 April 2022
Department of Science and Innovation	12 April 2022
The Automotive Industry Development Centre (AIDC)	14 April 2022*
Thabo Mtombeni	19 April 2022
Human Sciences Research Council/ Presidential Commission on the 4IR	10 May 2022
Industrial Development Corporation	18 May 2022
Industrial Development Corporation	18 May 2022
Industrial Development Corporation	18 May 2022

PRIVATE SECTOR	INTERVIEW DATE
Inqaba Biotechnical Industries (Pty) Ltd	12 April 2022
Aditiv Solutions	26 April 2022
Virecom	28 April 2022
Liqid Medical	03 May 2022

* No interview, written response via e-mail

A stakeholder validation workshop was also held on 30 May 2022 and involved 16 stakeholders from academia, government and the private sector. During this workshop the results of the project were presented. Comments and feedback on the results were received with a specific focus being given to the bottlenecks at different stages of the innovation lifecycle and the anomalies in the findings e.g. few fintech projects were identified.

QUALITATIVE DATA ANALYSIS

The qualitative data collected was codified in a series of interview notes/ full transcripts (where possible) and written notes of information found in written sources. Data analysis of these took three forms. Firstly, the data collected was sifted to develop an excel spreadsheet outlining details of all the invention education and support programmes that were identified. Second, the data was read and re-read to extract overarching themes relating to the research questions and the data inputted into a thematic matrix. This was then used to fill various sections of the final report.

QUANTITATIVE DATA ANALYSIS

The project team had access to a unique beta version of a dataset that measures and interprets the adoption of new and emerging technologies in the South African business sector. The survey covers four strategic sectors in Africa and South Africa in particular (agro-processing, textiles and apparel, auto manufacturing and ICT services. The survey is also tailored to the context of developing countries by including more accessible digital communication technologies, such as social media, internet surfing and online sales/ e-commerce, which can be seen as providing an 'entry-level' to more advanced technologies. As such, it is focused on 'emerging technology' when defined not simply as high tech or digital in characteristic.

Data from a total of 262 firms was analysed using non-parametric statistical methods.

LIMITATIONS

We have conducted a thorough review of the literature with in-depth analysis of over 100 references published in the last five years. However, we note that some of the results in the study are not consistent with the reality on the ground e.g. the lack of identification of fintech projects. We have attempted to mitigate this through a broad range of interviews and holding a validation workshop.

We also note that this report is focused on a snapshot of current/ recent projects in the emerging technologies space and is not an in-depth analysis of the field from a historical perspective. We have however focused on literature over the past five years (and particularly since the year before the PC4IR report) to try to ensure many projects and issues have been captured.

ANNEX 2: Actors in the emerging technology space in South Africa

Table 2.1: Government departments, agencies and bodies visible in emerging technologies

DEPT/AGENCY/BODY	EMERGING TECHNOLOGY	DESCRIPTION
Biosafety South Africa	- Biotechnology - Synthetic biology	Service platform within the national biotech innovation system supporting regulation, research and development and commercialisation of biotech products.
Department of Agriculture, Land Reform, and Rural Development	- Agro-processing - Synthetic biology	Key partner supporting the CSIR in its work in advanced agriculture and food.
Department of Energy	- Hydrogen technologies Micro-grids - Next-gene ration batteries	Department responsible for energy policy, regulation and development programmes.
Department of Environment, Forestry and Fisheries	- Agro-processing - Synthetic biology	Key partner supporting the CSIR in its work in advanced agriculture and food.
Department of Science and Innovation (DSI)	- Artificial intelligence - 3D printing - Gene drives - Hydrogen technologies - Energy storage - Next-generation medicine - Synthetic biology	Core state actor in South Africa's national innovation system engaging in a range of activities.
Department of Trade, Industry and Competition (DTIC)	- Automotive manufacturing - New materials	Department responsible for commercial and industrial policy.
Department of Transport	- Drones - Energy storage - Hydrogen technologies	Department responsible for transport policy, regulation and development programmes. Lead implementer of South Africa's Green Transport Strategy (2018).
Department of Water and Sanitation	- 3D printing - New materials - Water purification	Project partner with ASSAf to find water and sanitation solutions through 3D printing, linking structures and simulating various options.
National Department of Human Settlements (NDoHS)	- 3D printing	Department overseeing policy, legislation and programmes relating to human settlements. Lead partner in 3D printing projects for human settlements.
Technology Innovation Agency	- Artificial intelligence - Agro-processing - Biotechnologies - Next-generation medicine	National public entity supporting technology development through various mechanisms including funding.
The Automotive Industry Development Centre (AIDC)	- Automotive manufacturing	Provincial agency (Gauteng) supporting automotive competitiveness.

DEPT/AGENCY/ BODY	EMERGING TECHNOLOGY CLUSTER	DESCRIPTION
Academy of Science of South Africa (ASSAf)	3D printing Artificial intelligence Agro-processing Biotechnology Drones Energy storage Hydrogen technologies Next-generation medicine Water purification	Established in 1996. Remit extends to all fields of scientific enquiry. Represents South Africa in the international community of science academies. South African representative on the African Union High-Level Panel on Emerging Technologies.
Agriculture Research Council	Agro-processing Biotechnology	Key partner supporting the CSIR in its work in advanced agriculture and food.
Cape Peninsula University of Technology	Agro-processing	Hosts the AgriFood Technology Station (ATS) which provides services and laboratories for product development and testing.
Central University of Technology	3D printing Next-generation medicine	Host of the Centre for Rapid Prototyping and Manufacturing (CRPM). South Africa Research Chair in Innovation and Commercialisation of Additive Materials.
Centre for Artificial Intelligence Research (CAIR)	Artificial intelligence	Distributed South African research network, founded in 2011.
Council for Scientific and Industrial Research (CSIR)	3D printing Artificial intelligence Agro-processing Biotechnology Drones Energy storage Hydrogen technologies Next-generation medicine Medical devices Water purification	Research and development organisation; established in 1945 through an Act of Parliament. Key clusters include advanced agriculture and food, next generation health, smart mobility and manufacturing.
Durban University of Technology	3D printing Textiles Water purification	Supports the KZN Textile cluster. Awarded a South African Research Chair in the Institute for Water and Wastewater Technology.
Mintek	3D printing Nanotechnology Energy storage	South Africa's national mineral research organisation.
National Centre for Nano-structured Materials (NCNSM)	Nanotechnology	Established in 2007, NCNSM is housed at the CSIR and focuses on "design, modelling and synthesis of nanomaterials with specific properties and various possible applications".

DEPT/AGENCY/ BODY	EMERGING TECHNOLOGY CLUSTER	DESCRIPTION
National Research Foundation (NRF)	3D printing Artificial intelligence Agro-processing Biotechnology Drones Energy storage Hydrogen technologies New materials Next-generation medicine Water purification	Intermediary agency between the policies and strategies of the government and South Africa's research institutions. Established in 1999.
Nelson Mandela University	Next-generation medicine	Developed novel patented processes for two antiretroviral drugs.
North-West University	3D printing Artificial intelligence Hydrogen-related products	Co-host of Hydrogen South Africa Infrastructure. Hosts a CAIR learning node.
Rhodes University	Biotechnology	The Rhodes University Biotechnology Innovation Centre was established in 2014, providing a trans-disciplinary research and learning environment in the field of biotechnology.
Sol Plaatjie University	Artificial intelligence	Applied research in artificial intelligence (CAIR research group).
South African Medical Research Council	3D printing Biotechnology Diagnostic technologies Medical devices Next-generation medicine	The South African Medical Research Council (SAMRC) was established in 1969 with a mandate to improve the health of the country's population, through research, development and technology transfer.
South African National Energy Development Institute (SANEDI)	Energy storage Hydrogen technologies Micro-grids	Applied energy research and development, demonstration and deployment of sustainable energy in South Africa.
Stellenbosch University	3D printing Artificial intelligence Next-generation medicine Water purification	Participated in the EU-funded SafeWaterAfrica consortium consisting of ten academic and industrial partners from Germany, Italy and Spain and Mozambique; hosts the Biomedical Research Institute; developing metal additive manufacturing materials.
Tshwane University of Technology	Water purification	Participated in the EU-funded SafeWaterAfrica consortium consisting of ten academic and industrial partners from Germany, Italy and Spain and Mozambique.
University of Cape Town	Artificial intelligence Diagnostic technologies Energy storage Hydrogen technologies Medical devices Next-generation medicine	Hosts the Adaptive and Cognitive Systems Lab, research node for CAIR; research on catalysts and catalytic devices for fuel cells and hydrogen production (HySA); partner in the development of next-generation medicines, diagnostic technologies and medical devices.

DEPT/AGENCY/ BODY	EMERGING TECHNOLOGY CLUSTER	DESCRIPTION
University of the Free State	Biotechnology	Home to one node of the Industrial Biocatalysis Hub (IBH) which is an initiative of the Technology Innovation Agency (TIA) and the Department of Science and Innovation (DSI) and is hosted by the Council for Scientific and Industrial Research (CSIR).
University of Johannesburg	3D printing Artificial intelligence	Research partner exploring the use of 3D printing technologies in human settlements. UJ has introduced graduate and CPD courses on AI as well as research groups looking at AI for space science and the implications of machine learning on society, amongst others.
University of KwaZulu-Natal	Artificial intelligence 3D printing	CAIR group at UKZN conducts research in machine learning and deep learning; 3D printing projects in partnership with UJ and the KwaZulu-Natal and Western Cape provinces.
University of Limpopo	Artificial intelligence	Speech Technologies research group: CAIR note and affiliated with the Telkom Centre of Excellence for Speech Technology.
University of Pretoria	Artificial intelligence	CAIR research groups in data science, ethics of AI, and applied AI.
University of the Western Cape	Artificial intelligence Biotechnology Energy storage Hydrogen technologies Agro-processing	CAIR Research Group on Cybersecurity and Artificial Intelligence; host of Hydrogen South Africa Systems developing systems and prototypes (established 2007); supports the CSIR Industrial Biocatalysis Hub
University of the Witwatersrand	Gene drives Biotechnology	Hosts the Steve Biko Centre for Bioethics; conducting gene editing projects; supports the CSIR Industrial Biocatalysis Hub.
Vaal University of Technology	3D printing New materials	Additive Manufacturing centre focusing on tooling, shoe manufacturing and others.
Water Research Commission (WRC)	Water purification	Established in terms of the Water Research Act 34 of 1971, the WRC's functions include the funding of water research and the promotion of effective information and technology transfers.

Table 2.3: Sample of innovating firms visible in emerging technology clusters in South Africa

FIRM	EMERGING TECHNOLOGY	DESCRIPTION
Abalobi ICT4 Fisheries	- Mobile applications	Abalobi is a mobile app suite and non-profit programme. The Abalobi app is currently used by small-scale fishers along the South African coast and will soon be introduced to small- scale fishers in the Seychelles.
ADC Aeroswift	- 3D printing	Founded in July 2017. Developed world's biggest and fastest metal additive manufacturing powder bed machine (in conjunction with the CSIR).
Aditiv Solutions	- 3D printing	Tech start-up founded in 2019. Developed a local Hyrax metallic additive manufacturing machine (off shoot of the Aeroswift programme hosted by the CSIR).
Advance Call	- Water purification	Key partner in the EU-funded SafeWaterAfrica programme (42 months, beginning 1 June 2016) implementing a novel local water purification system.
AECI Limited	- New materials	Listed South African chemical group founded in 1924. Investing in research and development in new road materials in partnership with the CSIR through its AECI Much Asphalt's Central Laboratory.
Aerobotics	- Artificial intelligence - Drones - Mobile applications	Start-up founded in 2014, providing intelligent tools to the agriculture industry. Has raised $27m in funding since.
Afrigen Biologics and Vaccines	- Biotechnology - Nanotechnologies - Next-generation medicine	Cape Town-based biotechnology company founded in 2017. Part of WHO's mRNA consortium. Developed its own version of an mRNA COVID-19 vaccine.
AgriLED	- Automation software - Hydroponics	Supplier of off-grid sustainable agriculture systems, including hydroponics and automation within shipping containers. Founded in 2018. Received €500k funding in 2020.
AgriKool	- E-commerce	Developers of a digital platform providing smallholder farmers with finance and market linkage opportunities. Founded 2018. Part of AgriKool e-commerce business-to-business platform.
Altis Biology	- Biotechnology - Medical devices - New materials	Founded in c.f. 2002, specialises in research and development of osteogenic biomaterials for use in skeletal regeneration therapy. Its most recent innovation is the "novel loadbearing cancellous bone graft Alti Graft" launched in 2021.
Antrum Biotech	- Next-generation medicine	Antrum Biotech (Pty) Ltd was founded in 2008 as a spin-off company from the University of Cape Town to support the need for field-friendly rapid TB diagnostic tools in developing countries.
Aparito	- Medical devices	UK-based Aparito has developed a wearable device used for remote long-term epileptic patient monitoring outside of the hospital. The company is seeking partners to assist with market entry strategies into low- and middle-income countries, as well as partners for assistance in the broader expansion of the technology in other therapeutic areas in South Africa.
Avacare Healthcare Group	- Biotechnology - Next-generation medicine	Founded in 1996, Avacare have invested in Afrigen Biologics and Vaccines (founded in 2017), a biotechnology company which focuses on vaccines and vaccine adjuvants and encapsulations.
Balancell (Pty) Ltd	- Energy storage	Founded in 2003, battery manufacturer Balancell have developed a battery management system obtaining information about the performance of a battery and ensuring a longer battery lifespan.
Brayfoil Technologies (Pty) Ltd	- 3D printing - Morphing technologies	Founded in 2017. Partner with the Technology Innovation Agency to develop morphing wings that can be used in wind energy technologies for electricity production.
Cenfura	- Blockchain - E-commerce - Micro-grids	Blockchain platform developer partnering with DNA Global Energy on microgrid development (14) in South Africa (cf 2021). Owner of Malachite Mews microgrid in South Africa commissioned in 2020.
City Park Trading 127 CC	- Mobile application - Software application	Founded in 2003, City Park Trading has partnered with the Technology Innovation Agency to develop and commercialise a municipal water and sanitation management platform.
CLEVVA	- Artificial Intelligence	Artificial intelligence-based web platform developer founded in 2011. Recently partnered with UK-based robotic process automation (RPA) firm Blue Prism.
Cocos Solutions	- Nanotechnologies	Start-up company developing anti-icing and anti-pollution nano coating with applications in the energy industry.
CONDIAS GmbH	- Water purification	Key partner in the EU-funded SafeWaterAfrica programme (42 months, beginning 1 June 2016) implementing a new water purification system.
DC Geomatics (PTY) Ltd	- Drones	Founded in 2015; joint venture partner to develop drones for precision agriculture; launched first South African commercial operation in 2019.
De Novo Dairy	- Agro-processing - Biotechnology	Founded in 2021, De Novo Dairy focuses on producing non-animal dairy proteins using precision fermentation. Received two rounds of funding (2020, and 2021; undisclosed). Investors include CULT Food Science and Kale United (vegan start-up investor in Sweden).
DNA Economics	- Software application	Established in 2004, DNA Economics is a specialist economic and development consulting firm. Current recipient of funding from South Africa-UK Partnering for Accelerated Climate Transitions Programme for its tool to facilitate the incorporation of climate-related financial risks and opportunities into financial decision making.
Engie SA	- Micro-grids - Energy storage	French multinational energy utility, participating in the development of large-scale storage systems; equity investments in energy companies.
Eskom Holdings SOC Ltd -	- Micro-grids	To support its transition away from coal, Eskom has announced the development of a flagship micro grid (c.f. 2021). Eskom developed a pilot microgrid in 2018.

DEPT/AGENCY/ BODY	EMERGING TECHNOLOGY CLUSTER	DESCRIPTION
Free Radical Design Process (FRPD)	- Processing technologies	FRPD is an engineering consultancy specialising in process engineering, operating in the mining sector. Founded in 2015, the company has co-developed a novel processing technology for extracting minerals from mining wastewater.
Gknowmix -	- E-commerce	Integrated system for genetic testing service delivery involving healthcare practitioners, medical scientists, laboratories and the public. Gknowmix was founded in 2007 as a spin off company from the South African Medical Research Council.
HaloCare (Pty) Ltd	- E-commerce	Managed care organisation founded in providing disease management services. Key investor in online wellness platform developer, Syked.
HealthLeap	- Diagnostic technologies - Mobile applications	Founded in 2021, HealthLeap is a South African health tech firm focusing on the US market.
House4Hack	- 3D printing	Local informal incubator and co-learning workspace for technology specialists and entrepreneurs.
HyPlat	- Energy storage - Hydrogen technologies	HyPlat is a proudly South African specialist fuel cell technology company delivering best in class membrane electrode assemblies and platinum group metals catalysts to the low temperature polymer electrolyte membrane fuel cells sector.
Hyrax Biosciences	- Automation software - Cloud-computing	Patented cloud-based software platform enabling the use of DNA sequencing for low cost, highly scalable diagnostics, translating complex DNA sequence data into clinically actionable reports.
I-G3N	- Energy storage	Founded in 2018, I-G3N is a manufacturing start-up that assembles Lithium Phosphate batteries. The company's core market is on stationary storage in conjunction with Solar PV.
Impala Refinery Services	- Energy storage - Hydrogen technologies	Leading global platinum mining company. Investor in AP Ventures Fund II for hydrogen technologies.
Inqaba Biotechnical Industries (Pty) Ltd	- Synthetic bio	Founded in 2002. One of two sizable synbio operations (the other is Stellenbosch). Financed through private equity from 30 private shareholders and through a loan from the Swiss government
Jendamark	- Artificial intelligence - Industrial robots	Port Elizabeth-based international technology company, established in 1998. Commissioned to build one of the first autonomous electric vehicle (EV) assembly lines for a Silicon Valley startup (cf 2019).
Jirehsa Medical (Pty) Ltd	- Medical devices	Founded in 2006, Jirehsa Medical (Pty) Ltd has developed an internationally patented, low cost, disposable medical device for retaining either endotracheal tubes or laryngeal mask airways during anesthesia.
Khepri Innovations	- Biotechnology	Khepri Innovations is a biotechnology company established in 2012. The company has developed trademarked feedstocks and offers consulting services for waste management and disposal.
Khula App (Pty) Ltd	- E-commerce	ICT start-up launched in 2018, developing platforms for the agricultural industry.

DEPT/AGENCY/ BODY	EMERGING TECHNOLOGY	DESCRIPTION
Kusini Water	- Internet of Things Things - Nanotechnology - Water purification	Founded in 2017, Kusini manufactures and assembles water filtration and treatment systems. Secured funds (undisclosed amount) from Vumela Fund, announced 1 December 2021.
Lepsta (Pty) Ltd	- Optical imaging technologies - Sensor technologies - Blockchain technologies - Software automation	Founded in 2017 Leptsa offers an automatic coding platform to assist developers collaborate effectively and minimise errors through automation. Co-developer and commercial partner of the Optronic Sensor System for tracking drones and other objects on land, air and sea.
Life Assay Diagnostics	- Diagnostic technologies	Antimonia is a point of care diagnostic system/ solution for differential diagnosis of bacterial and viral pneumonia in under 40 minutes. Undergoing clinical trials.
Liqid Medical	- Medical devices	Novel ocular implant designed to improve the treatment of glaucoma. Funding has been approved to support device refinement, clinical trials, and regulatory certification. Development began in 2015; received funding in 2019 from SAB Foundation.
Lodox Systems	- Biomedical imaging	Lodox Systems produces full body X-ray imaging devices for medical use in trauma and forensic pathology centres using ultra-low X-ray doses for frequent and rapid scanning. Founded in 2002.
Lonmin plc	- 3D printing	Joint venture by Lonmin and the Central University of Technology, North-West University and Vaal University of Technology initiated in 2016 for to develop 3D printing machinery and materials for platinum jewellery.
Lula Loop (Pty) Ltd	- E-commerce	Founded in 2016, Lula connects commuters to private shuttles. In 2017, the company raised R316k through crowdfunding. In 2020, they received an undisclosed amount from Harambeans and TotalEnergies Ventures.
MALII Fintech	- E-commerce - Mobile banking/ mobile money	Start-up MALII Fintech has developed an app that enables taxi commuters to make payments without using cash. Currently being piloted in Gauteng province with plans to scale nationwide.
Medsol AI Solutions	- Artificial Intelligence - E-commerce	Medsol's Breast AI Solution is software designed for breast cancer identification and segmentation for breast ultrasound in the diagnostic imaging sector. Received funding in 2021 from SAB Foundation.
Mellowcabs	- E-commerce - Energy storage	Mellowcabs manufactures light electric cargo vehicles for emission-free delivery services in cities. Offers bespoke, client-specific offerings like active cooling and security features. Founded in 2013.
Microsoft South Africa	- Artificial intelligence - Big data - Cloud computing	Microsoft South Africa has funded the development of agricultural applications of HYDRA technology, developed by start-up The Awareness Company (founded 2017).
Msizi Pharmaceutical Holdings	- Next generation medicine	Msizi Pharmaceutical Holdings has been supported by TIA to develop Flucytosine, which is recommended by the World Health Organization as part of the treatment for cryptococcal meningitis.

DEPT/AGENCY/ BODY	EMERGING TECHNOLOGY CLUSTER	DESCRIPTION
New Horizons Waste to Energy	-- Waste-to-energy	Processing organic municipal waste to produce biogas, fertiliser and carbon dioxide (and other) products. Received funding from the IDC in 2020.
NovelQuip Forestry	- Silviculture technologies	NovelQuip has developed a silviculture planting solution for the commercial forestry industry that combines seedling extraction, soil preparation, gel/ water application, fertiliser application, seedling planting, weedicide application, and soil firming.
PACSys (PTY) Ltd	- Drones	Farmer-owned organisation established in 2016 to research, develop and distribute precision agricultural technologies. PACSys / DC Geomatics JV was the first SACAA approved commercial drone spraying operation in RSA (2019).
Poynting Group	- Wireless technologies	Founded in 2001, Poynting design and manufacture technically excellent wideband antennas. Technologies developed with the Technology Innovation Agency. Currently operating in 70 countries with offices in Germany and the US.
Retecon (PTY) Ltd	- 3D printing	Established in 1970, providing Additive Production Systems in South Africa.
ROC Water Technologies	- Water purification	ROC Water are specialists in mine water treatment. Founded in 2016, Roc Water Technologies has developed a unique, low-cost solution to produce drinking water and other valuable products from acid mine water.
RTS Africa Engineering	- Hydrogen technologies	Founded in 2015, RTS Africa Engineering is a supplier and distributor of components for hydrogen production.
Scout Technologies (Pty) Ltd	- Automation software	PharmaScout offers temperature equipment, mapping, calibration and monitoring solutions for medical industry compliance. Established in 2018, PharmaScout is a subsidiary of healthtech firm 5nines Technologies and has recently been awarded financing (undisclosed) from Knife Capital.
SENER	- Energy storage	Joint venture between SENER and ACCIONA providing engineering, procurement and construction services for Kathu Solar Park CSP Plant (cf 2018). SENER has been working in South Africa since 2013.
Sinapi Biomedical	- Medical devices	Sinapi Biomedical (Pty) Ltd based in Stellenbosch, South Africa, are advancing the use of the Ellavi UBT in conjunction with PATH. In February 2018, Sinapi Biomedical obtained a certificate of free sale from the South African National Department of Health to sell and to export the product.
Shanti Natural Care	- Cosmetic technologies	Producer of cosmetics, using fynbos, essential oils, indigenous herbs, honey and CBD found in the cannabis plant. Founded c.f. 2019.
Solar Biotech (Pty) Ltd	- Optical imaging technologies	Commercial partner of the CSIR for its novel fingerprint system to acquire the fingerprints of corpses. Founded c.f. 2007.

FIRM	EMERGING TECHNOLOGY	DESCRIPTION
SolarReserve LLC	- Energy storage	Developer of utility-scale solar power projects and advanced solar thermal technology. Owns Kalkaar Molten Salt Thermal Energy Storage System (50%) and Rooipunt Molten Salt Thermal Energy Storage System (50%). (cf 2015)
Startupbootcamp AfriTech	- Financial technologies	Cape Town-based multi corporate-backed pan-African start-up accelerator launched in 2017. Provides access to a global network of corporate partners, investors, and mentors.
SwiftVee	- E-commerce	Online auction platform for buying and selling livestock products, founded in 2017.
Syked	- E-commerce	Online wellness platform that connects clients to a network of vetted and qualified therapists via video call, text and telephonic support. Founded in 2019, awarded the Development Award by the SAB Foundation in 2022, receiving R450 000 in grant funding as well as access to mentorship.
Tectra Automation	- Diagnostic technologies	Tectra Automation is a supplier of assembly, production and manufacturing solution. Founded in 1978, the company has partnered with Eskom SOC Holdings Limited and Nelson Mandela University to develop a novel diagnostic machine.
TeleSensi	- Artificial Intelligence - Diagnostic technologies	TeleSensi CARDIAC is a stand-alone, cloud-based, artificial intelligence murmur detection service. TeleSensi was founded in 2007.
Tessara (Pty) Ltd	- Biotechnology	Founded in 2015, Tessara (Pty) Ltd specialises in sulphur-dioxide packaging for perishables. Licensee commercialising a natural fumigant developed by ARC and that acts against spoilage agents when fresh produce is transported over long distances.
The Awareness Company	- Artificial intelligence - Big data - Cloud computing	Founded in 2018, this start-up uses data-driven storytelling to create solutions for agriculture, conservation, safety and security, and smart buildings and cities. Awarded funding from Microsoft (undisclosed) in 2022, under its Agri-tech programme.
The South African Nuclear Energy Corporation SOC Ltd (NECSA)	- Nuclear technologies	The South African Nuclear Energy Corporation is a public company wholly owned by the state, established in 1999 by the Republic of South Africa Nuclear Energy Act. Its mandate includes applied research and development and commercial application of nuclear and associated technology
TokaBio (Pty) Ltd	- Diagnostic technologies	Founded in 2016, TokaBio (Pty) Ltd specialises in diagnostics assays and platform development. 4IR-enabled point of care diagnostics can diagnose foot-and mouth disease in the field where livestock are kept, including remote locations
Truzo (Pty) Ltd	- Mobile banking/ mobile money	Truzo, a digital escrow platform, acts as a trusted third-party payment provider to both buyers and sellers of online and real-world transactions. Founded in 2016, Truzo also offers a multi-currency solution via its UK-domiciled office.
Urban Farms Recycling (Pty) Ltd	- Waste management technologies	Founded in 2013, Urban Farms Recycling specialises in commercial and residential food waste management. The company's vermiculture facility in Modderfontein is the largest of its kind in South Africa.

FIRM	EMERGING TECHNOLOGY CLUSTER	DESCRIPTION
Vantage Health Technologies	- Artificial intelligence - Cloud computing	Vantage Health Technologies, a South Africa-based company provides cloud-based solutions for health equity challenges. Partnering with Microsoft, Vantage uses artificial intelligence to translate health data into actionable insights.
Virecom	- Video relay services	Founded in 2015, Virecom provides high definition, instant, convenient and affordable Video Remote Interpreting (VRI) services using online video technology, with real-time text and voice simultaneously at the touch of a button. Awarded R500 000 in grant funding in the Disability Empowerment Awards category in 2020.
VulAmanz Water Filters	- New materials - Water purification	VulAmanz, with support from the Technology Innovation Agency, has developed a novel water purification filter utilising a locally developed woven polyester microfiltration membrane. Successfully piloted in 2017.
Wamly	- Automation software	One-way interview software for HR applications. Founded in 2018. Announced funding secured from Knife Capital in 2022 (details not disclosed).
Wongeta	- Optical imaging technologies	Wongeta is a SME founded in 2015, specialising in finance technology. The company is the first user of a novel CSIR visitor identification system under the terms of a pilot license. The company used the system to authenticate recipients of funds using biometrics.
Xineoh	- Artificial intelligence - Big data	Founded in 2017, Xineoh engineering is run by its founder Vian Chinner, out of Johannesburg, South Africa (headquartered in Canada). Predicts customer behaviour using artificial intelligence. Xineoh has raised US$3.5 million since inception.
Yoco Technologies	- E-commerce - Mobile banking/ mobile money	African technology company founded in 2013, providing access to offline and online payments for small and independent businesses. Yoco has raised US$102 million in financing since inception.

Table 2.4: *Global and regional initiatives in emerging technologies in which South Africa is participating*

INITIATIVE	EMERGING
African Association of Automotive Manufacturers	The African Association of Automotive Manufacturers works with African governments to unlock economic potential and promote the automotive sector across the continent.
African Biosafety Network of Expertise (ABNE)	The objective of the ABNE service network is to build functional regulatory systems in Africa. ABNE biosafety services include information resources; training and education (workshops, short courses, on-line courses, internships, and regulatory study tours); technical support, networking.
African Biosciences Initiative (ABI)	In a drive to harness science and technology, African leaders adopted a Science and Technology Consolidated Plan of Action (CPA). One of the flagship programmes of the CPA is the African Biosciences Initiative (ABI) which focuses on research and development (R&D) in the areas of biotechnology, biodiversity, indigenous knowledge systems and technology.
African Medicines Regulatory Harmonization (AMRH)	AMRH supports Regional Economic Communities (RECs) and regional organisations (ROs) to develop and implement programmes for harmonising standards, operating procedures, and related policies and legislation on medical products regulation.
African Union High-Level Panel on Emerging Technologies (APET)	APET, as a pathfinder think tank and strategic initiative of AUDA-NEPAD, advises the AU and its member states on harnessing emerging technologies for economic development.
COMESA-EAC-SADC Tripartite	The COMESA-EAC-SADC Tripartite brings together nearly 600 million people and close to half of Africa's countries with the objective of strengthening and deepening their economic integration.
Elimination Eight Initiative	The Elimination Eight Initiative (E8) is a coalition of eight countries working across national borders to eliminate malaria in southern Africa by 2030.
NANOsciences AFrican NETwork (NANOAFNET)	NANOAFNET, the NANOsciences AFrican NETwork, an initiative created in 2005 in Trieste-Italy under the patronage of the Abdus Salam ICTP, UNESCO, IAEA, TWAS and the ICS-UNID, and supported by several international agencies, is the African continental voice in the emerging field of nanoscience and nanotechnology.
Network of African Science Academies (NASAC)	NASAC's main objective is to bring together science academies and facilitate discussions on the scientific aspects of challenges of common concern, so as to make common statements on major issues relevant to Africa and to provide mutual support to member academies.
Southern Africa Network for Biosciences (SANBio)	The Southern Network for Biosciences (SANBio) is a shared biosciences research, development and innovation platform for working collaboratively to address some of southern Africa's key biosciences issues in health, nutrition and health-related intervention areas such as agriculture and environment.
The African Centre for eHealth Excellence	The African Centre for eHealth Excellence (Acfee) is a non-profit organisation based in South Africa. The Centre's Advisory Board comprises 12 senior people in healthcare from 11 countries. The core aims of Acfee are to develop eHealth leadership and expand eHealth capacity for sustainable eHealth initiatives.
The Smart Africa Alliance	The Smart Africa Alliance is a partnership among 32 African countries adhering to the Smart Africa Manifesto. The Smart Africa Alliance and member states, supported by stakeholders such as academia, private sector, and civil society, drafted an Artificial Intelligence Blueprint.
The World Academy of Sciences Sub-Saharan Africa Regional Partner (TWAS-SAREP)	The World Academy of Sciences Sub-Saharan Africa Regional Partner (TWAS-SAREP) is one of five regional offices of The World Academy of Sciences (TWAS). TWAS-SAREP has been hosted by the Academy of Science of South Africa (ASSAf) since March 2015.
United Nations Framework Convention on Climate Change	The United Nations Framework Convention on Climate Change (UNFCCC) is an international treaty aimed at achieving stabilisation of the concentration of greenhouse gases (GHG) in the atmosphere to mitigate and prevent anthropogenic interference in the global climate system. South Africa ratified the UNFCCC on 29 August 1997 and became a Party to this Convention on 27 November 1997. South Africa is listed as a Non-Annex I country.

Table 2.5: Examples of partnerships, consortiums and joint ventures in various emerging technology clusters in South Africa

INITIATIVE	TECHNOLOGY CLUSTER	DESCRIPTION
Advanced Agriculture and Food Cluster, Council for Scientific and Industrial Research	Drones Agro-processing Diagnostic technologies Next-generation medicine	The cluster focuses on agro-processing, precision agriculture, business model innovation and food safety through robotics and sensor technologies, green energy and packaging solutions, diagnostic tools, vaccines and biofertilisers. Key partners in the cluster include the Council for Scientific and Industrial Research; Department of Energy; Department of Environment, Forestry and Fisheries; Department of Agriculture, Land Reform, and Rural Development; the Agriculture Research Council; and the National Research Foundation
Aeroswift project	3D printing	Aerosud Innovation Center, and the South African Council for Scientific and Industrial Research (CSIR) partnered on the South African Aeroswift project. Launched in 2011, the partnership developed the Aeroswift printer which would be the largest metal additive manufacturing system on the market.
African Hydrogen Partnership Trade Association (AHP)	Hydrogen technologies	Continent-wide African umbrella association. Dedicated to the development of green and natural hydrogen, hydrogen-based chemicals, hydrogen fuel cell technologies in Africa.
Automotive Supply Chain Competitiveness Initiative (ASCCI)	Automotive manufacturing	ASCCI is described as a national non-profit initiative, established by government, industry and labour. The initiative aims to facilitate supplier competitiveness improvement initiatives in the South African automotive industry.
Biosafety South Africa and ISAAA AfriCenter	Synthetic Biology	ISAAA is a not-for-profit international organisation that shares crop biotechnology with stakeholders, such as resource-poor farmers in developing countries.
Cape Clothing and Textile Cluster (CCTC)	New materials	The CCTC is a not-for-profit initiative jointly established by government and industry in 2005 to boost the competitiveness of the clothing, textile, footwear and leather (CTFL) manufacturing industry in the Western Cape.
CLEVVA (Pty) Ltd	Artificial intelligence	CLEVVA has partnered with UK-based robotic process automation (RPA) firm Blue Prism (as a technology partner).
Diagnostic multi-camera project	Optical imaging technologies	This project is a joint collaboration between TIA, the Council for Scientific and Industrial Research (CSIR), and Eskom, who have come together to develop world-class technology to monitor potential power line failures using a phenomenon known as corona discharge
National Department of Human Settlements and Department of Water and Sanitation	3D Printing	Inter departmental partnership to develop water and sanitation solutions through 3D printing. Incluedes National Home Builders Registration Council (NHBRC) to incorporate the 3D aspect into policies while exploring partnerships with the Architecture Institute and architectural firms using 3D technology to upgrade informal settlements
NovelQuip Ponsse Oyi	Silviculture technologies	Partnership between NovelQuip and Finnish-based original equipment manufacturer Ponsse Oyj to further develop a novel silviculture planting solution technology to support global adoption and diffusion.
PACSys (PTY) Ltd and DC Geomatics (PTY) Ltd JV	Drones	The first SACAA approved commercial drone spraying operation in RSA (2019).
PATH Sinapi Biomedical	Medical devices	Partnership between PATH and Sinapi Biomedical to support the commercialisation and diffusion of a medical device. This project was funded with aid from the UK government.
PlatForum	3D Printing	Partnership between the Central University of Technology, North-West University, Vaal University of Technology, and platinum producer Lonmin initiated in 2016 to develop additive manufacturing techniques for jewellery.
Post-Harvest Innovation (PHI) Programme	3D Printing	Partnership between the Central University of Technology, North-West University, Vaal University of Technology, and platinum producer Lonmin initiated in 2016 to develop additive manufacturing techniques for jewellery.
Post-Harvest Innovation (PHI) Programme	Agro-processing	The Post-Harvest Innovation (PHI) Programme is a public-private partnership between the Department of Science and Innovation (DSI) and the Fresh Produce Exporters' Forum (FPEF), with the FPEF as the implementing partner. The programme has a wide remit including facilitating cross-sector research and innovation projects and mobilising resources for the fruit sector's research and innovation system.
Tessara (Pty) Ltd Agriculture Research Council Council for Scientific and Industrial research	Biotechnology	A consortium between the Agriculture Research Council and the Council for Scientific and Industrial Research has entered into a materials transfer/ licensing agreement with Tessara (Pty) Ltd to commercialise a natural fumigant to prevent spoilage during long-distance transport.
UK PACT uYilo eMobility Programme	E-commerce Energy storage Mobile applications	Partnership between uYilo, Cenex UK and UK PACT. uYilo was confirmed as a partner in February 2021, to build capacity and knowledge on electric transportation.
Vantage Health Technologies Microsoft South Africa	Artificial intelligence Cloud computing	Partnering with Microsoft, Vantage uses artificial intelligence to translate health data into actionable insights for payers, providers and government health organisations serving underserved populations.

ANNEX 3: Incentives available for emerging technology firms in South Africa

Table 3.1. Tax incentives available to emerging technology firms

TAX INCENTIVE	MANAGING NATIONAL DEPARTMENT	DETAILS
12L: Tax Allowance Incentive	National Treasury	The 12L Tax Incentive is designed to support Greenfield investments (i.e., new industrial projects that utilise only new and unused manufacturing assets), as well as Brownfield investments (i.e., expansions or upgrades of existing industrial projects). The incentive offers support for both capital investment and training with a special focus on promotion of energy efficient technologies.
Section 11D: Research and Development Incentive (R&D)	South African Revenue Service	Section 11D allows a deduction equal to 150% of expenditure incurred directly for R&D and an accelerated depreciation deduction (that is, 50:30:20) for capital expenditure incurred on machinery or plant used for R&D.
Section 12R: Special Economic Zone (SEZ)	Department of Trade and Industry	Section 12R provides the designation of special economic zones (SEZ) offering a reduced corporate tax rate along with other incentives offered to firms operating within a designated SEZ. Zones are designated by the Minister of Trade and Industry and approved by the Minister of Finance

Table 3.2. Debt, equity and blended finance facilities available from the South African government

FACILITY	PRIMARY FUNDER	DETAILS
AFD Green Energy Fund	Industrial Development Corporation	Debt finance for renewable energy and energy efficiency projects of smaller scale and manufacturing of green products in South Africa. Instruments and pricing. Total investment cost not higher that 25% of the facility (ca R250 million per project).
Clothing, Textiles, Footwear and Leather Growth Programme (CTFLGP)	Department of Trade, Industry and Competition	Debt finance for capital equipment as well as people, product, process and market development improvement for brownfield or greenfield interventions to a maximum of R20 million per applicant.
Khoebo Innovation Promotion Programme (KIPP)	Industrial Development Corporation	Medium to long-term financing with strong risk-taking features, e.g., grant, equity, quasi-equity and subordinated loans. Maximum funding per transaction set at R7 million.
Small Enterprise Manufacturing Support Programme	Department of Small Business Development	Debt finance. Maximum of R15 million per small enterprise. Blended finance instrument will be utilised where up to 50% of the funding required could be a grant (soft loans) and the balance could be a loan.
The Agri-Industrial Fund	Industrial Development Corporation	Debt finance to develop competitive, economically viable activities in agro-processing (food and non-food) sectors by developing local and regional resources to supply domestic demand and increase international trade.
The Manufacturing Competitiveness Enhancement Programme (MCEP)	Department of Trade, Industry and Competition	Pre/ post-dispatch working capital facility offers up to a maximum of R30 million for a period of up to four years, at a preferential fixed interest rate of 6%.
TIA Sector Funding	Technology Innovation Agency	Blended finance instruments available in the natural resources, energy, information communication and technology, and advanced manufacturing sectors.

Table 3.3. Infrastructure and services support available from the South African government

PROGRAMME/ FACILITY	MANAGING BODY	DETAILS
Basic Entrepreneurial skills Development (BESD)	Small Enterprise Development Agency (SEDA)	The programme is designed to transfer basic business skills to micro-business owners during weekly two-hour one-on-one training and coaching sessions at their business premises over a period of approximately 15 months.
Biomanufacturing Industry Development Centre	Council for Scientific and Industrial Research	To translate biomanufacturing concepts and technologies into market-ready products and services.
Biorefinery Industry Development Facility	Council for Scientific and Industrial Research	Development and testing of biorefinery technologies in the South African context.
Global Cleantech Innovation Programme	Technology Innovation Agency	The Global Cleantech Innovation Programme (GCIP) supports entrepreneurs in growing their small, medium and micro enterprises (SMMEs) and start-ups into viable, investment-ready businesses.
Imvelisi's Enviropreneur Programme	Department of Science and Innovation	Ideation and early-stage business development platform, offering young innovators access to resources and mentorship.
Incubation programmes	Small Enterprise Development Agency (SEDA)	72 SEDA supported incubators available to small micro and medium enterprises to support growth. Each of the 72 SEDA supported incubators has its own incubatee recruitment and selection process that is unique to their sector.
Industrial Biocatalysis Hub	Council for Scientific and Industrial Research	Technical product and process development support to enterprises in the biomanufacturing sector using biocatalysis technologies.
Innovation Skills Programme	Technology Innovation Agency	To stimulate and strengthen critical thinking capabilities to enable innovation to occur and support the progression of technologies from proof-of-concept stage through to pre-commercialisation.
Nanomaterials Industrial Development Facility	Council for Scientific and Industrial Research	Services and facilities available to firms to produce and test nanomaterials at industrial scale.
Photonics prototyping facility	Council for Scientific and Industrial Research	Facilities, technical support, equipment and scarce skills to assist in industrialising these untapped technologies.
Youth Technology Innovation Programme	Technology Innovation Agency	Business support and advisory services: regular structured one-on-one sessions or training aimed to provide the recipient with necessary business knowledge, tools and competencies to develop sustainable techno-enterprises.

Table 3.4 *Designated Special Economic Zones and clusters in South Africa*

ECONOMIC ZONE	LOCAL OR PROVINCIAL GOVERNMENT AUTHORITY	DETAILS
Atlantis SEZ	City of Cape Town	The Atlantis SEZ is part of the City of Cape Town's initiative of 2011 to establish a greentech manufacturing hub in Atlantis for: solar energy; biofuels; CSP hybridisation; wind energy; water; waste
Coega IDZ	Nelson Mandela Bay Metropolitan Municipality	The Coega IDZ is the largest IDZ in southern Africa. It was designated in 2001 and became South Africa's first Industrial Development Zone. The IDZ has attracted investment in the agro-processing, automotive, aquaculture, energy, metals logistics and business process services sectors.
Dube TradePort SEZ	KwaZulu-Natal Provincial Government	Areas that have been designated as the Industrial Development Zone are the Dube TradeZone and the Dube AgriZone. The Dube TradeZone – aims to focus on manufacturing and value-addition primarily for automotive, electronics and fashion garments. The Dube AgriZone – a high-tech farming facility and host to the continent's largest climate-controlled growing area under glass – will focus on high-value, niche agricultural and horticultural products.
East London IDZ	Buffalo Municipality	The ELIDZ is a prime industrial site in South Africa. It is geographically designated and positioned for specialised industrial activity. The zone was specially set up for light industry manufacturers in search of ultimate global competitiveness and new market entry.
Ekurhuleni Aerotropolis	City of Ekurhuleni, Gauteng	Ekurhuleni Aerotropolis is an initiative to stimulate passenger travel and air cargo growth. The city seeks investments for its 30-year masterplan and is inviting private investors, funding institutions, property developers and commercial institutions to unlock the potential of the region.
Jewellery Manufacturing Precinct	Gauteng Growth and Development Agency	GIDZ initiated the establishment of the Jewellery Manufacturing Precinct which became operational from 2021. It is located within the OR Tambo International Airport Special Economic Zone, which is strategically established to facilitate the manufacturing and export of high value, light mass products via airfreight.
Maluti-a-Phofung SEZ	Harrismith, Free State	This newly established SEZ offers exporters a logistics base that facilitates access to the Port of Durban, and intermodal logistics solutions for the transfer of freight between road and rail. The zone is well-suited and licensed for general manufacturing, offering a convenient production base for light and medium manufacturing.
Medical Manufacturing Cluster	Gauteng Growth and Development Agency	The Gauteng IDZ has identified 29 ha of land in OR Tambo International Airport Precinct ("ORTIA Precinct 2") to set up a medical manufacturing cluster. This is an approximately R4,2billion (USD 289,6 million) development located adjacent to the OR Tambo International Airport.
Musina/ Makhado SEZ	Limpopo Economic Development Agency	The Musina/ Makhado SEZ comprises two geographical locations that address unique industrial clusters. The site in Musina targets the light industrial and agro-processing clusters, while the Makhado site is a metallurgical/ mineral beneficiation complex. A third site has been identified to target the petrochemical industries.
Nkomazi Special Economic Zone (SEZ)	Nkomazi Local Municipality	Nkomazi Special Economic Zone has been formalised to provide a competitive and highly efficient industrial cluster that positions itself as the leading location for agro-processing, and logistics services activities within South Africa, in response to investor demand.
OR Tambo IDZ	Gauteng Growth and Development Agency	Gauteng Industrial Development Zone was established to manage the establishment and operationalisation of the OR Tambo International Airport SEZ (ORTIA SEZ). Incentives including employment tax incentive, Value Added Tax exemption and duty-free importation of production related material and assets.
Richards Bay Industrial Development Zone (RBIDZ)	Richards Bay Municipality	Situated on the Northern Coast of South Africa, the Richards Bay Industrial Development Zone Company (SOC) Ltd (RBIDZ) is a designated Special Economic Zone aimed at international competitiveness, encouraging trade for the attraction of international and domestic investments.
Saldanha Bay Industrial Development Zone	Saldanha Bay	It is envisioned that this newly established IDZ will serve as the primary oil, gas and marine repair engineering and logistics services complex in Africa, servicing the needs of the upstream oil exploration industry and production service companies operating in the oil and gas fields off sub-Saharan Africa.
The Tshwane Automotive Special Economic Zone (TASEZ)	City of Tshwane	The Tshwane Automotive Special Economic Zone is Africa's First Automotive City.
Vaal SEZ	Gauteng Growth and Development Agency	The Vaal area of Gauteng has for decades been a hub for manufacturing, heavy industrial and engineering, and has identified land parcels set to be developed into a multi-site, multi-sector focused Special Economic Zone. The aim of the Vaal SEZ is to grow the agricultural, manufacturing, logistics and renewable energy sectors.

Table 3.5. *Grant funding available from the South African government*

FACILITY	PRIMARY FUNDER	DETAILS
Agro-Processing Support Scheme	Department of Trade, Industry and Competition	The scheme offers a 20% to 30% cost-sharing grant to a maximum of R20 million over a two-year investment period, with a last claim to be submitted within six months of the final approved milestone.
Automotive Investment Scheme (AIS)	Department of Trade, Industry and Competition	The AIS provides for a non-taxable cash grant of 20% of the value of qualifying investment in productive assets and 25% of the value of qualifying investment in productive assets by component manufactures and tooling companies as approved by the DTIC.
Clothing, Textiles, Footwear and Leather Growth Programme (CTFLGP)	Department of Trade, Industry and Competition	Capital equipment as well as people, product, process and market development improvement for brownfield or greenfield interventions to a maximum of R20 million per applicant with 25% of funding as grant. At the end of capital moratorium, on achieving targets set at application, a further 25% is convertible to a grant
Critical Infrastructure Programme (CIP)	Department of Trade, Industry and Competition	The CIP offers a grant of 10% to 30% of the total qualifying infrastructural development costs, up to a maximum of R50 million, based on the achieved score in the Economic Benefit Criteria.
Export Marketing & Investment Assistance Scheme (EMIA)	Department of Trade, Industry and Competition	Provides marketing assistance to develop new export markets and grow existing export markets; Assists with the identification of new export markets through market research. Assists companies to increase their competitiveness by supporting patent registrations, quality marks and product marks.
Innovation for Inclusive Development	Department of Science and Innovation	Grant funding for technology diffusion, technology development, IP support, business development support, and market access opportunities for grassroots innovators.
Khoebo Innovation Promotion Programme (KIPP)	Industrial Development Corporation	The programme provides medium to long-term (long-term limited by the term of the fund) financing with strong risk-taking features, e.g., grant, equity, quasi-equity and subordinated loans. Providing medium to long-term low-cost funding with a maximum funding per transaction set at R7 million.
Pre-commercialisation Support Fund	Technology Innovation Agency	Funding for individual entrepreneurs and SMEs to support pre-commercialisation activities including the development of production/ service capacity to levels that will support operational sustainability.
Production Incentive Programme (PIP)	Department of Trade, Industry and Competition	Clothing, textiles, footwear, leather & leather goods manufacturing industries funding assistance to invest in competitiveness improvement interventions. The PIP consists of two components, namely an Upgrade Grant Facility and an Interest Subsidy for Working Capital Facility.
SEDA Technology Programme (STP) – Quality Standards and Technology Transfer Fund	Small Enterprise Development Agency (SEDA)	To enhance the competitiveness and sustainability of small enterprise in South Africa by promoting quality and excellence as competitive tools for SMMEs, cooperatives and incubators in realising their short-, medium- and long-term strategic objectives. A maximum amount of R600 000 can be requested and needs to be motivated by demonstrating return on investment.
Seed Fund	Technology Innovation Agency	To enable innovators to evaluate, demonstrate and advance the value proposition and commercial potential of their research outputs. Grant funding of up to R650 000 per application will be allocated together with the specified conditions around monitoring and evaluation.
Small Enterprise Manufacturing Support Programme	Department of Small Business Development	Maximum of R15 million per small enterprise. Blended finance instrument will be utilised where up to 50% of the funding required could be a grant (soft loans) and the balance could be a loan.
Special Economic Zone Fund	Department of Trade, Industry and Competition	A SEZ fund intends providing multi-year funding for SEZ infrastructure and related operator performance improvement initiatives aimed at accelerating growth of manufacturing and internationally traded service operations, to be located within the designated zones.
Strategic Partnership Programme (SPP)	Department of Trade, Industry and Competition	Grant funding for capital expenditure, infrastructure, product/ service development, ICT, operational costs and business development services. Approval is capped at a maximum of R15 million (VAT inclusive) per financial year over a three year period towards qualifying costs, based on the number of qualifying suppliers and is subject to the availability of funds
Support Programme for Industrial Innovation (SPII)	Department of Trade, Industry and Competition	The provision of financial assistance for the development of innovative products and processes. SPII is focused specifically on the development phase. It includes the product process development scheme: R2 million (maximum grant) and the matching scheme: R5 million (maximum grant).
Technology and Human Resources for Industry Programme (THRIP)	Department of Trade, Industry and Competition	HRIP is a cost-sharing grant of up to R5 million per annum for a maximum period of three years for approved projects engaged in applied research and development in science, engineering and/ or technology.
Technology Development Fund	Technology Innovation Agency	The Technology Development Fund provides funding to advance technologies from proof of concept to technology demonstration.
The Agri-Industrial Fund	Industrial Development Corporation	The Agri-Industrial Fund aims to develop competitive, economically viable activities in agro-processing (food and non-food) sectors by developing local and regional resources to supply domestic demand and increase international trade. The grant cannot be used on its own but in conjunction with IDC funding
Workplace Challenge Programme (WPC)	Department of Trade, Industry and Competition	The WPC assists South African manufacturing, agriculture and agro-processing, mining and beneficiation businesses. Managed by Productivity South Africa the WPC aims to actively encourage, and support negotiated workplace change to enhance productivity and competitiveness.
Youth Technology Innovation Programme	Technology Innovation Agency	Grant funding of up to R1 million per transaction. This programme is designed to assist young innovators to access risk funding, mentorship and business skills support.

ANNEX 4: Funding of Emerging Technologies

Table 4.1: 2021 Africa venture capital equity funding by market

	NIGERIA	SOUTH AFRICA	EGYPT	KENYA	SENEGAL	GHANA	
Fintech	1 320,6	588,7	294,0	245,4	331,9	97,0	2 877,6
Enterprise	35,0	63,8	25,6	96,0	1,7	4,9	227,0
E/M/S/Commerce	80,7	4,8	156,5	10,3	1,7	1,2	255,1
Health Tech	44,2	77,4	32,8	20,0	—	50,2	224,5
Logistictech	38,3	1,2	64,5	8,1	2,4	10,1	124,6
Edtech	240,5	27,5	10,9	4,5	—	0,3	283,6
Cleantech	5,5	17,1	—	69,3	14,2	—	106,0
Agritech	21,0	2,5	1,5	91,1	0,9	2,4	119,3
Entertainment	4,4	7,6	20,6	1,0	—	—	33,6
Mobility	3,0	15,5	30,5	2,0	0,2	—	51,2
Insurtech	4,3	21,7	2,6	2,3	—	0,7	31,5
Connectivity	1,5	0,9	2,8	21,0	—	—	26,1
Hw & Electronics	0,2	3,0	9,4	—	—	—	12,6
TOTAL GENERAL	**1 799,2**	**831,5**	**651,6**	**570,9**	**352,8**	**166,6**	**4 372,6**

Source: Reproduced from Assou et al. (2022, p.24)

Table 4.2: Partially disclosed funding transactions in emerging technology clusters in South Africa

PROJECT/ INVESTMENT	FUNDER(S)	TECHNOLOGY	DETAILS
ACWA Power Solafrica Bokpoort CSP Power Plant Pty Ltd	- Investec Bank Limited	- Energy storage	R5 billion refinancing of Bokpoort Power Plant cf. 2021.
Aerobotics	- Naspers Foundry (lead) - Cathay AfricInvest Innovation, - FMO: Entrepreneurial Development Bank - Platform Investment Partners	- Artificial Intelligence - Drones - Mobile applications	South African start-up, founded in 2014 providing tools for precision agriculture. The company has raised US$27 million, with the latest round of US$17 million announced in January 2021.
Aerosud Holdings (Pty)	- Industrial Development Corporation	- 3D printing	R135 million industry and project development funding Aerosud Holdings (Pty) co-developer of the Aeroswift 3D printer (with CSIR). Awarded July 2020.
AgriLED	- Hivos Impact Investments	- Automation software - Hydroponics	EUR 500,000.00 to start-up AgriLED, announced in February 2019.
Altis Biologics	- Technology Innovation Agency	- Biotechnology - Medical devices - New materials	The TIA has committed R45 million to the Altis Osteogenic Bone Matrix to assist Altis Biologics to build a pilot plant, train an operations team, conduct clinical trials, obtain regulatory approval and commence small-scale production.
Balancell (Pty) Ltd	- Technology Innovation Agency	- Energy storage	Awarded R11 million to develop the technology, and follow-on funding for technology development and commercialisation activities.
HealthLeap	- Fifty Years (VC)	- Diagnostic technologies - Mobile applications	US$1.1 million pre-seed funding to develop a clinical aid for dieticians (focus on US market). Announced 6 January 2022.
I-G3N	- ASISA Enterprise and Supplier Development - Edge Growth - Secha Capital	- Energy storage	ASISA ESD initiative partnered with Secha Capital, an impact fund manager to provide R1.3 million to start-up battery manufacturer I-G3N.
Khula App (Pty) Ltd	- AECI - E-Squared Investments	- E-commerce - Mobile applications	US$1.3 million seed round to scale operations awarded circa 2021.
Lodox Systems	- Technology Innovation Agency - Industrial Development Corporation	- Biomedical imaging	R12 million commitment from TIA and R30 million from the IDC for the development of Lodox's next generation X-ray machines in 2020/2021.
Nanotechnology Flagship Project (NFP)	- National Research Foundation	- Nanotechnology	Since inception of the NFP funding instrument in 2007, the NRF has reported an investment of R57 million in 25 research grants.
New Horizons Waste to Energy (Pty) Ltd	- Industrial Development Corporation	- Waste-to-energy	R1.341 million project financing for New Horizons awarded 11 January 2021.
NovelQuip Forestry	- Technology Innovation Agency	- Silviculture	R12.8 million funding awarded to NovelQuip to develop its silviculture plant solution for commercial forestry. NovelQuip has applied for a further R30 million, for additional development work and pre-commercial activities.

PROJECT/ INVESTMENT	FUNDER(S)	TECHNOLOGY	DETAILS
Optishunt (Liqid Technologies)	- Technology Innovation Agency	- Medical devices	Funding commitment of R9.4m over three years to support device refinement, clinical trials, and regulatory certification.
Revego Africa Energy Limited (Revego)	- Investec Bank Limited - UK Climate Investments LLP (UKCI)	- Renewable energy technologies	R1 billion commitment to renewable energy investment vehicle Revego (2019) for renewable-energy projects in South Africa.
ROC Water Technologies	- Water Research Commission - A-Thermal	- Water purification	Founded in 2016, ROC Water received R2.7 million in grant funding from the WRC on 22 May 2019. Earlier rounds of seed funding in 2018 totalled R4 million.
Stellenbosch University	- Department of Higher Education	- Biotechnology - Next-generation medicine	R300 million funding contribution to the construction of the Biomedical Research Institute at the University of Stellenbosch (Total cost R1 billion). Construction began in 2019.
swiftVEE	- Subtropico	- E-commerce	Subtropico announced US$1.5 million to agri-tech start-up swiftVee in 2020 to facilitate expansion into southern Africa
University of Cape Town's (UCT) Electrolyser Research Group	- Federal Ministry of Education and Research (BMBF), Germany	- Hydrogen technologies	Funding of approximately R3 million secured from Germany's Federal Ministry of Education and Research (BMBF) for a two-year project to advance its electrolyser catalyst-coated membranes (CCMs) used for hydrogen production.
Yoco Technologies	- Dragoneer Investment Group - Velocity Capital Fintech Ventures - Partech (and seven others)	- Mobile banking/ mobile money	Fintech company Yoco Technologies raised US$83 million in July 2021. This was their sixth round of funding since seed funding was raised in 2014.

ANNEX 5: Stages of Development

Table 5.1: Emerging technologies in the discovery phase per sector of application

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Agriculture, forestry and fishing	IoT-based irrigation management system	- Automation software - Internet of Things	- Council for Scientific and Industrial Research - Tshwane University of Technology - Bahir Dar University - Dedan Kimathi University of Technology - Haramaya University - Turku	Resource-efficient Internet of Things architecture is developed that monitors soil, microclimate and water parameters and performs appropriate irrigation management. Data processing, network management, irrigation decisions and communication to the farmers are carried out locally, without the involvement of any back-end servers.
Agriculture, forestry and fishing	Vacuum Ultraviolet Photolysis	- UV technology	- Agricultural Research Council - Cape Peninsula University of Technology - Leibniz-Institute for Agricultural Engineering and Bioeconomy - Post-Harvest Innovation (PHI) Programme	Vacuum ultraviolet (VUV) photolysis is an emerging technology with promising characteristics for ethylene and microbial management. An alternative technology in postharvest ethylene management
Construction	3DCP Concrete printing	- 3D printing	- Department of Science and Innovation - University of KwaZulu-Natal	Basic and applied research of concrete printing (and other building materials). Pilot project implementation in KZN will focus on innovation of all construction elements (3D printed walls and other building elements using other forms of innovation). Includes exploring opportunities to develop customised materials using local and waste materials.
Electricity, gas, steam and air	Blockchain powered energy network	- Blockchain	- University of Johannesburg - University of Cape Town	Distributed blockchain-based architecture model for balancing and managing microgrids in a smart grid. Elements of the microgrid and their functionality have been simulated.
Electricity, gas steam and air	Catalysts and catalytic devices for hydrogen production	- Energy storage - Hydrogen technologies	- University of Cape Town - Department of Science and Innovation - Mintek	The HySA Catalysis Competence Centre housed at the University of Cape Town. Its mandate is to develop materials, components and units to support the fuel cell and hydrogen generation value chain.

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Electricity, gas, steam and air	Hydrogen Infrastructure	- Hydrogen technologies	- North-West University, Hydrogen South Africa Infrastructure	Basic and applied research in technologies for hydrogen, production, storage and distribution. Part of Hydrogen South Africa Programme.
Electricity, gas, steam and Air	Nuclear	- Nuclear technologies	- The South African Nuclear Energy Corporation SOC Ltd (NECSA)	Applied research and development and commercial application of nuclear and associated technology
Electricity, gas, steam and air	Smart Distribution Network System (SDNS)	- Automation software - E-commerce	- University of Johannesburg	Smart Distribution Network System to control and manage energy usage from the consumption side. Digitalised electrical network concept that allows the existing power network to operate at an optimum level during peak periods and limits unnecessary consumption excesses. Simulation tests have been conducted.
Human health and social work	3D bioprinting	- 3D printing	- North-West University - Centre for Scientific and Industrial Research CSIR)	Resource-efficient Internet of Things architecture is developed that monitors soil, microclimate and water parameters and performs appropriate irrigation management. Data processing, network management, irrigation decisions and communication to the farmers are carried out locally, without the involvement of any back-end servers.
Human health and social work	Prosthetics and medical devices	- 3D printing	- Central University of Technology - Centre for Rapid Prototyping and Manufacturing - Department of Science and Innovation - Manufacturing, Engineering and Related Services Sector Education and Training Authority Sector Education and Training Authority	Basic and applied research at the Central University of Technology's Centre for Rapid Prototyping and Manufacturing. Developing medical prosthetics. CUT holds a research chair in Innovation and commercialisation of AM.

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Information and communication	Artificial intelligence	- Artificial intelligence	- Centre for Artificial Intelligence Research (CAIR) - Sol Plaatjie University - Stellenbosch University - University of Cape Town - University of KwaZulu Natal - University of Limpopo - University of Pretoria - North-West University	Basic and applied research in artificial intelligence including machine learning, deep learning, knowledge representation and reasoning and speech technology. The Centre for Artificial Intelligence Research (CAIR) was founded in 2011 and has established nodes and research networks with universities.
Manufacturing	Agro-processing	- Agro processing	- Cape Peninsula University of Technology, AgriFood Technology Station - University of Limpopo, Limpopo Agro-Food Technology Station - Technology Innovation Agency Department of Science and Innovation	Basic and applied research in agro-processing technologies. Testing and laboratory services.
Manufacturing	Biocatalysis	- Biotechnology	- CSIR Industrial Biocatalysis Hub - Mintek - Rhodes University - University of the Free State - University of Fort Hare - University of the Western Cape	Basic and applied research on biocatalysis; entails the use of enzymes and microorganisms in manufacturing processes to produce products such as industrial biologics, biopharmaceuticals and bio-veterinary compounds
Manufacturing	Catalysts and catalytic devices for hydrogen fuel cell production	- Hydrogen technologies	- University of Cape Town - Department of Science and Innovation - Mintek	The HySA Catalysis Competence Centre housed at the University of Cape Town. Its mandate is to develop materials, components and units to support the fuel cell and hydrogen generation value chain.
Manufacturing	Friction processing technologies	- Processing technologies	- Nelson Mandela University, eNtsa Innovation Hub - National Research Foundation - Sasol Limited - Eskom Holdings SOC Ltd - The Electrotechnical Skills Partnership (TESP)	Research and development of friction processing technologies including friction stir welding, friction hydro pillar processing, friction taper hydro pillar welding and friction welding (including boss welding, friction stud welding and hexagonal bar welding).
Manufacturing	Nanomaterials	- Nanotechnologies - New materials	- National Centre for Nano-structured Materials (NCNSM) - Department of Science and Innovation - Centre for Scientific and Industrial Research (CSIR)	Basic and applied research on design, modelling and synthesis of nanomaterials with specific properties and various possible applications. Initial focus is on carbon nanotubes, silicon nanoparticles and nanolayer deposition techniques.

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Manufacturing	Nanotechnologies	- Nanotechnologies	- Centre for Artificial Intelligence Research (CAIR) - Sol Plaatjie University - Stellenbosch University - University of Cape Town - University of KwaZulu-Natal - University of Limpopo - University of Pretoria - North-West University	Basic and applied research in artificial intelligence including machine learning, deep learning, knowledge representation and reasoning and speech technology. The Centre for Artificial Intelligence Research (CAIR) was founded in 2011 and has established nodes and research networks with universities.
Transport and storage	New age modified emulsion (NME) nanotechnology	- Nanotechnologies	- University of Pretoria	NME nanotechnology for the stabilisation of granular materials for the construction of roads. Nanotechnology solutions are used to stabilise, enhance, and improve naturally available materials. Proven in laboratories, through accelerated pavement tests (APT) in the field as well as in practice.
Agriculture, forestry and fishing	Multivalent inactivated vaccine against heartwater	- Next generation veterinary medicine	- Agriculture Research Council - CIRAD (France) - CIRDES (Burkina Faso) - IBET (Portugal) - LEAP-Agri	Production of a high-quality, heat-stable, affordable multivalent inactivated vaccine against heartwater (HW) to support sustainable agriculture for smallholder farmers. MuVHA project will test vaccines in field conditions in Burkina Faso and South Africa.
Agriculture, forestry and fishing	Non-thermal plasma technology	- Mobile applications - Sensor technologies	- Nelson Mandela University - LEAP-Agri - Soil Research Institute (Ghana) - National Agricultural Research Organisation (Uganda) - Eindhoven University of technology (Netherlands) - Associação Fraunhofer Portugal Research (Portugal)	On-site fertiliser production mini-plants to provide affordable fertiliser. Combined with the development of sensors and ICT technology to enhance the quality of soil and food production. Research is based on nitrogen fixation with non-thermal plasma technology. Project being tested at plants built in Uganda, South Africa and Ghana.
Construction	3D printed houses	- 3D printing	- University of Johannesburg - Department of Science and Innovation - Department of Human Settlements	Project involving a partnership between the DSI and UJ to research the potential of 3D printing of houses and the implementation of a pilot 3D housing project in a selected province. Research and develop materials suitable for 3D printing of houses using local materials and waste materials. Pilot 3D printing on a real project comprising 50 houses.

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Electricity, gas, steam and air	Biogas-from-waste	- Waste-to-energy	- New Horizons Energy - African Oxygen - Waste Mart - Fountain Civil Engineering (Pty) Ltd - Industrial Development Corporation	Biogas production plant under construction in Cape Town, Western Cape. Processing of municipal sewerage waste and pure organic waste to produce biogas. waste to produce biogas.
Electricity, gas, steam and air	Morphing wing	- Morphing technology - 3D printing	- Brayfoil Technologies (Pty) Ltd - Technology Innovation Agency	Development of morphing wing that can be used in wind energy technologies for electricity production. Morphing wings change their shape from symmetrical to cambered, depending on the prevailing wind conditions.
Financial and insurance activities	Investment decision-making tool	- Software application	- DNA Economics	A tool for companies and financial institutions to effectively consider climate-related financial risks and opportunities (CFROs) when making investment decisions. Funded by the South Africa-UK Partnering for Accelerated Climate Transitions Programme.
Financial and insurance activities	Web-based legal services	- Mobile money/ banking	- Keakopa - Consumatech	Web-based solution that allows users to create simple contracts when lending money to friends and family. Also supports debt recovery services. Developed by Keakopa, supported by Consumatech.
Human health and social work	3-Tiered Smart Screening Cascade for Malaria	- Diagnostic technologies	- Centre for Scientific and Industrial Research (CSIR) - National Health Laboratory Service - South African Medical Research Council - University of Pretoria	An in vitro platform for use to screen transmission-blocking antimalaria compounds against gametocytes and gametes. The South African Malaria Transmission-Blocking Consortium is looking for partnerships for the screening and identification of transmission-blocking antimalarial compounds.
Human health and social work	Antimonia	- Diagnostic technologies	- Life Assay Diagnostics - South African Medical Research Council	Antimonia is a point-of-care diagnostic system for differential diagnosis of bacterial and viral pneumonia in under 40 minutes. Undergoing clinical trials. Developer Life Assay Diagnostics have secured manufacturers and are seeking potential customers to assist with market entry in low resourced and middle-income countries.

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Human health and social work	Aspalathin therapeutic preparations	- Next-generation medicine	- South African Medical Research Council	Aspalathin-rich green rooibos extract (GRT Extract) and synthetic aspalathin as novel therapeutic preparations for the treatment and management of metabolic disease. Phase one trials completed.
Human health and social work	Bi-SP microbicide complex	- Next-generation medicine	- National Health Laboratory Service - South African Medical Research Council	Bi-SP complex is a low-cost, stable, rapidly solubilised active pharmaceutical ingredient that can be formulated into a microbicide with low toxicity towards mammalian cells and vaginal Lactobacillus clinical strains and broad microbicidal activity against most sexually transmitted pathogens, including HIV. Patent applications will be filed once the structural characterisation and in vivo studies have been completed.
Human health and social work	Cardioflow	- Diagnostic technologies	- Technology Innovation Agency	Portable, hand-held, point-of-care (PoC) screening device able to identify patients at risk of cardiovascular disease. The project has now reached the clinical trial phase. The local market includes approximately 4 200 primary health care clinics in South Africa
Human health and social work	Flucytosine	- Next-generation medicine	- Msizi Pharmaceutical Holdings - Nelson Mandela University - Technology Innovation Agency	Msizi Pharmaceutical Holdings is developing Flucytosine, a recommended treatment for cryptococcal meningitis by the World Health Organization. Commercialisation of novel patented processes for two antiretroviral drugs developed at Nelson Mandela University.
Human health and social work	Marker serum proteins for early-stage diabetes	- Diagnostic technologies	- South African Medical Research Council	The technology includes two marker serum proteins for the early detection of people at risk for diabetes. Patent applications to be filed once the prototype device has been developed and validated. Further optimisation of the device is in progress, after which it will be validated on clinical samples.

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Human health and social work	Medsol Breast AI	- Artificial intelligence - E-commerce	- Medsol AI Solutions - SAB Foundation	Online patient-based platform that receives images for ultrasound units in practice. Software designed for breast cancer identification and segmentation for breast ultrasound in the diagnostic imaging sector using deep machine learning and artificial intelligence. Received funding in 2021 from SAB foundation.
Human health and social work	mRNA Covid vaccine	- Biotechnology - Next-generation medicine	- Afrigen Biologics and Vaccines - Avacare Healthcare Group - Industrial Development Corporation	mRNA vaccine developed by Cape Town-based biotechnology company Afrigen Biologics. The company was founded in 2017, supported and capitalised by Avacare Healthcare Group and the Industrial Development Corporation. Clinical trials are underway.
Human health and social work	NutriLeap	- Diagnostic technologies - Mobile applications - Artificial intelligence	- HealthLeap	Founded in 2021, HealthLeap is a South African health tech firm focusing on the US market. Awarded US$1.1 million pre-seed funding by venture capitalist Fifty Years to develop a clinical aid for dieticians with a focus on US market. Announced 6 January 2022.
Human health and social work	PrCr Urine dipstick text	- Diagnostic technologies	- South African Medical Research Council	A Protein/Creatinine rapid test for determining proteinuria status as onset indicator of Preeclampsia/ Eclampsia. Currently undergoing clinical testing.
Human health and social work	Prosopis Glandulosa	- Next-generation medicine	- South African Medical Research Council	A cost-effective, novel therapeutic agent for treating contused muscle tissue and recovering skeletal muscle strength. Animal studies have been completed.
Human health and social work	Roboleg	- 3D printing	- House4Hack - Robohand	3D printed prosthetic leg to mitigate the high costs of current prosthetics. Developed in collaboration with Robohand Cape Town, Australia and Robohand HQ. Developed and rolled out.

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Human health and social work	TB SERS Biosensor	- Diagnostic technologies	- University of Cape Town - South African Medical Research Council	TB SERS Biosensor is a novel, hand-held, battery operated POC TB diagnostic device. The University of Cape Town is seeking funding for component integration, prototype development and validation (field testing and clinical accuracy) of the diagnostic platform.
Information and communication	Fingerprint system	- Optical imaging	- Council for Scientific and Industrial Research - Solar Biotech (Pty) Ltd	Fingerprint system uses optical coherence tomography, a non-invasive imaging system that uses light waves to capture micrometer-resolution images. A means of acquiring fingerprints from corpses. The technology enables the acquisition of both internal and surface fingerprints simultaneously to get an accurate print to match against a database. Currently being tested.
Information and communication	Semiconductor chip	- Semi-conductor technologies	- Multifractal Semiconductors (Pty) Ltd - Technology Innovation Agency - University of Pretoria	Partnership with the University of Pretoria and Multifractal Semiconductors (Pty) Ltd to develop fully integrated E-band front ends on a single chip in silicon. Useful for building cheaper wireless communication equipment such as 5G transmitters and automotive radar systems.
Manufacturing	Catalyst-coated membranes	- Hydrogen technologies - New materials	- University of Cape Town - Hyplat - Federal Ministry of Education and Research, Germany - Mintek - Leibniz University Hannover, Institute of Electric Power Systems	The RAINBOW project, 'Reaction kinetic improvements by using novel catalyst layers for proton exchange membrane (PEM) water electrolysis' aims to support African project partners with contract research for commercialisation.
Manufacturing	Nano coatings	- Nanotechnologies - New materials	- Cocos Solutions	Anti-icing and anti-pollution nano coating with applications in the energy industry.
Manufacturing	Non-animal dairy proteins	- Biotechnology	- De Novo Dairy - CULT Food Science - Kale United	Development of nature identical, animal free proteins for human nutrition. Founded in 2021, De Novo Dairy is developing non-animal dairy proteins using precision fermentation.

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Transport and storage	Sustainable road surfacing	- New materials	- Centre for Scientific and Industrial Research (CSIR) - AECI Much Asphalt's` Central Laboratory	Road surfacing technology using locally available micro-fillers and recycled tyres to pave roads. Tested in a controlled trial section in Roodepoort, Gauteng.
Water supply, sewerage and waste management	Autonomous water purification system	- New materials	- Advance Call (Pty) Ltd - Council for Scientific and Industrial Research - Stellenbosch University - Tshwane University of Technology - Virtual Consulting Engineers (Pty) Ltd - CONDIAS GmbH - Fraunhofer IST - University of Castilla La Mancha - University of Ferrara	The SafeWaterAfrica project aims to develop, introduce and apply a new and autonomous water purification system using adapted European low-energy water treatment technology.
Water supply, sewerage and waste management	Luminophospher power treatment	- Processing technologies	- eWaste Africa - Innovation Hub Climate Innovation Centre South Africa - Technology Innovation Agency - University of KwaZulu-Natal	Novel technology to extract rare metals and mercury from the luminophospher power in lighting waste. Prototype chemical process LXP Plant being developed in conjunction with the University of KwaZulu-Natal supported by the Technology Innovation Agency.
Water supply, sewerage and waste management	Municipal water and sanitation leaks management platform	- Mobile applications - Software applications	- City Park Trading 127 CC - Technology Innovation Agency	An app system to be used by municipalities to monitor and manage water and sanitation faults to reduce water and improve responses to water and sanitation faults. Currently being developed and tested.

Table 5.310: Emerging technologies in the commercialisation phase per sector of application

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Agriculture, forestry and fishing	Biocontrol Sheet	- Biotechnology	- Agricultural Research Council - Centre for Scientific and Industrial Research - Technology Innovation Agency - Tessara (Pty) Ltd	ARC and CSIR have successfully developed a natural fumigant that acts against spoilage agents when fresh produce is transported over long distances. ARC and CSIR consortium entered into a materials transfer/ licensing agreement with Tessara (Pty) Ltd (a South African company) for the commercialisation of the developed technology.
Agriculture, forestry and fishing	HYDRA Holistic Agriculture and HYDRA Conversation	- Artificial intelligence - Big data - Cloud computing	- The Awareness Company (Pty) Ltd - Microsoft South Africa	Founded in 2018, the company uses data-driven storytelling combining AI, IoT and data analytics to create solutions for agriculture and conservation, safety and security, and smart buildings and cities. Microsoft South Africa has funded the development of agricultural applications of its HYDRA technology.
Agriculture, forestry and fishing	In-field prototype fuel consumption meter	- Sensor technologies	- Agricultural Research Council	Developed by ARC, the prototype fuel consumption meter developed provides a reliable, compact, easy-to-use tool for farmers, implement manufacturers and other stakeholders to measure real-time fuel consumption to monitor fuel efficiency and evaluate tractor-implement performance.
Agriculture, forestry and fishing	Postharvest processing solution	- Processing technologies	- Agricultural Research Council	Postharvest treatment for isolated funders to de-husk and dehydrate macadamia nuts. Rolled out to 27 small-scale farmers in Limpopo province.
Agriculture, forestry and fishing	Silviculture planting solution	- Silviculture technologies	- NovelQuip Forestry - Technology Innovation Agency - Industrial Development Corporation	A fully mechanised silviculture planting solution for the commercial forestry industry that combines seedling extraction, soil preparation, gel/ water application, fertiliser application, seedling planting, weedicide application, and soil firming. Partnering with global OEM Ponsse Oyji to rather develop technology and market and distribute globally.
Electricity, gas, steam and air	Battery management system	- Energy storage	- Technology Innovation Agency - Balancell (Pty) Ltd - Department of Trade and Industry	Battery management system obtaining information about the performance of a battery and ensuring a longer battery lifespan. Funding secured from the Support Programme for Industrial Innovation.
Electricity, gas, steam and air	Open power watch (OPW)	Internet of Things Sensor technologies	- House4Hack	OPW leverage IoT designs and technologies to measure the voltage and temperature at street-level substations and mini substations. Can monitor loading, outages and supply quality.
Electricity, gas, steam and air	Solar-powered microgrid	- Micro-grids	- Eskom - Department of Agriculture, Forestry and Fisheries	Flagship solar-powered microgrid project to replace Komati coal-fired power plant due to be decommissioned in 2022. Pilot demonstration of 14 households, conducted in 2018, using lithium-ion batteries.
Human health and social work	Aparito's Atom5™	- Medical devices	- Aparito - South African Medical Research Council - University of Cape Town	Wearable device used for remote long-term epileptic patient monitoring outside of the hospital and developed by UK-based Aparito. The technology developers are seeking partners to assist with market entry strategies into LMICs, as well as partners for assistance in the broader expansion of the technology in other therapeutic areas in South Africa.
Human health and social work	Ellavi Uterine Balloon Tamponade (UBT)	- Medical devices	- Sinapi Biomedical - South African Medical Research Council - PATH	The Ellavi UBT is a preassembled medical device that is manufactured by Sinapi at their ISO 9001 and 13485 certified factories. The innovators are seeking international partners to assist with market entry strategies into LMICs, as well as partners for assistance with regulatory approvals of the device in Africa.

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Human health and social work	Endotrachea tube-retaining device	- Cloud computing - Software applications	- Jirehsa Medical (Pty) Ltd - South African Medical Research Council	Patents on the device have been granted in European designated countries (UK, France, Germany, Spain, Ireland and Italy) as well as South Africa, Australia and the USA. The technology developers are seeking partners for the commercialisation and international marketing of the product as an intubation device to be used in the anesthesiology and emergency medical services sectors.
Human health and social work	Exatype	- Diagnostic technologies	- Hyrax Biosciences - South African Medical Research Council	Patented cloud-based software platform enabling the use of DNA sequencing for low-cost, highly scalable diagnostics, translating complex DNA sequence data into clinically actionable reports. Seeking funders interested in social impact and advocacy with global public health groups, government and key stakeholders.
Human health and social work	GIFT Genital Inflammation Test	- Mobile applications	- University of Cape Town - South African Medical Research Council	A low-cost, point-of-care test to identify genital inflammation associated with sexually transmitted infections in symptomatic and asymptomatic individuals. Has undergone clinical trials. National phase patent applications are pending. The technology developers seek commercialisation partners for the technology.
Human health and social work	MomConnect	- Diagnostic technologies - Medical devices	- National Department of Health	South African National Department of Health initiative, launched in 2014, to support maternal health through the use of cell phone-based technologies integrated into maternal and child health services.

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Human health and social work	Optishunt	- Medical devices	- Liqid Medical - SAB Foundation - Technology Innovation Agency	Novel ocular implant designed to improve the treatment of glaucoma. Funding has been approved to support device refinement, clinical trials, and regulatory certification.
Human health and social work	Pharmascout	- Nanotechnologies - New materials	- Scout Technologies - 5nines Technology - Knife Capital	PharmaScout, a division of Scout Technologies, offers temperature equipment, mapping, calibration and monitoring solutions for medical industry compliance. In 2018, venture capital firm Knife Capital made an undisclosed investment to help grow the business.
Human health and social work	Rat eradication gadget		- The Hamelin - Imvelisi's Enviropreneur Programme	Mass rat eradication gadget. Poison-free trap hat can be installed on the ground. Successfully installed and tested in an informal settlement in South Africa.
Human health and social work	Syked Online Mental Wellness services	- E-commerce	- Syked - HaloCare Disease Management - SAB Foundation - Umthombo Youth Development Foundation - Health and Welfare Sector Education and Training Authority	Online wellness platform that connects clients to a network of vetted and qualified therapists via video call, text and telephonic support. Awarded grant funding and mentorship support from SAB Foundation in 2020.
Human health and social work	TB-PROTEC	- Diagnostic technologies	- Antrum Biotech (Pty) Ltd - South African Medical Research Council - University of Cape Town	Field-friendly rapid TB diagnostic tools in developing countries. Antrum Biotech (Pty) Ltd was founded in 2008 as a spin-off company from the University of Cape Town
Human health and social work	Umbiflow™	- Diagnostic technologies	- Centre for Scientific and Industrial Research (CSIR) - South African Medical Research Council - University of Cape Town - World Health Organization - Bill and Melinda Gates Foundation - National Department of Health India	A novel portable continuous-wave Doppler ultrasound to be used in remote areas and primary health care settings. Currently undergoing tests for market access. Technology available for licensing.

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Human health and social work	Vantage health equity dashboard	- Artificial intelligence - Cloud computing	- Vantage Health Technologies - Microsoft	Vantage Health Technologies, a South Africa-based company that provides cloud-based and AI solutions for health equity challenges. Announced US launch in 2021. Key partners include Microsoft.
Human health and social work	Video Remote Interpreting (VRI) services	- Video relay services	- Virecom Video Remote Communications - SAB Foundation	Video Remote Interpreting (VRI) services using online video technology, with real-time text and voice simultaneously, complemented by a mobile app. Received funding from the SAB Foundation in 2019 to support commercialisation and further development.
Electricity, gas, steam and air	Diagnostic multi-camera	- Optical imaging technologies	- Technology Innovation Agency - Eskom SOC Holdings Ltd - Council for Scientific and Industrial Research	Multi-functional diagnostic camera system used for fault detection on high-voltage power lines. This new technology will be used to support companies in the maintenance of its high-voltage powerline infrastructure. Successfully developed and tested.
Information and communication	Integrated recognition system	- Optical imaging technologies	- Council for Scientific and Industrial Research	The CSIR-developed system comprises independent recognition systems that can be integrated to collaboratively solve physical security and surveillance problems. It uses camera imaging technology, integrated with CSIR-developed modules for face and human body recognition. First point of deployment in October 2020 at the South African Army Headquarters.
Information and communication	Optronic Scene Simulator (OSSIM)	- Software application	- Council for Scientific and Industrial Research	OSSIM is an engineering development tool developed to meet this need. The simulator is written in C++ and runs on Windows and Linux systems. Current applications are mainly in the defence domain, but OSSIM can be applied in the civilian world.

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Information and communication	Optronic Sensor System	- Optical imaging technologies - Sensor technologies	- Council for Scientific and Industrial Research	Local system developed to track drones and other objects on land, air and sea: platform for the integration and testing of tracking algorithms for slow to fast-moving small targets at long ranges. The directional optical countermeasure system has been tested and evaluated against a drone target.
Information and communication	Spacedecode	- Software application	- Lepsta (Pty) Ltd - Technology Innovation Agency - Geekulcha - WeThink Code	Self-managed software development platform which enables collaboration and real-time sharing of source code between developers. Enabling coding, correction, and agile deployment of quality-assured software amongst software developers.
Information and communication	Stand Alone Tracker (SAT)	- Optical imaging technologies	- Council for Scientific and Industrial Research	A high bandwidth pan-tilt unit that uses some of these algorithms to track single targets in real-time. Integrated with radar systems and consists of high resolution visual and infrared sensors that can be pointed at targets with high precision.
Information and communication	VeristicPrint Biometric Technology	- Optical imaging technologies	- Technology Innovation Agency - Council for Scientific and Industrial Research - Wongeta	Contactless fingerprint technology for mobile devices: system to authenticate recipients of funds using biometrics. The contactless fingerprint technology enables imaging devices such as smartphones, webcams and digital cameras to be used as fingerprint scanners and can be integrated into existing biometric systems. Currently being piloted.
Information and communication	Video Remote Interpreting (VRI)	- Video relay service	- Video Remote Communications (Virecom) - SAB Foundation	Video Remote Interpreting (VRI) services using online video technology, with real-time text and voice simultaneously at the touch of a button. Hearing and deaf persons are in the same location, whilst the VRI is located remotely at the Virecom call centre. Awarded funding from SAB Foundation.

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Information and communication	Wide Area Surveillance System	- Artificial intelligence - Optical imaging technologies	- Council for Scientific and Industrial Research	Used in the detection of small craft in the maritime environment, specifically in support of anti-piracy operations. Omni-directional viewing capability, with the ability to perform real-time stitching, background modelling and target tracking.
Manufacturing	Additive manufacturing power bed machine	- 3D printing	- ADC Aeroswift - Aerosud Innovation Centre - Centre for Scientific and Industrial Research (CSIR) - Department of Science and Innovation	The Aeroswift project has developed the world's biggest and fastest metal-additive powder bed manufacturing system to produce metal parts for the commercial aerospace manufacturing sector. The project was funded by the Department of Science and Innovation. Proof of concept has been completed, with three components manufactured.
Manufacturing	Battery electric scooters	- Hydrogen technologies	- University of the Western Cape, Hydrogen South Africa Systems - Department of Science and Innovation	Battery electric scooters powered by hydrogen fuel cells, launched in 2019. Will be rolled out to the South African postal services (SAPO).
Manufacturing	CBD and indigenous herbs care products	- Cosmetic technologies	- Shanti Natural Care	Hand-crafted natural healing products, including creams, soaps and tinctures, using fynbos, essential oils, indigenous herbs, honey and CBD found in the cannabis plant. Developed, tested and commercialised.
Manufacturing	Hyrax machine	- 3D printing	- Aditiv Solutions - ADC Aeroswift - Centre for Scientific and Industrial Research (CSIR) - Department of Science and Innovation	Laser powder bed Hyrax metallic AM machine. Developed by local company Aditiv Solutions founded in 2019. The machine was demonstrated in 2021 with a small number of pre-production machines to order for Nelson Mandela University.

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Manufacturing	PGM and MEA catalysts	- Energy storage - Hydrogen technologies	- HyPlat - University of the Western Cape, Hydrogen South Africa Systems - University of Cape Town, Centre for Catalysis Research - Mintek - Technology Innovation Agency - Impala Platinum Refineries - PowerCell Sweden	Platinum group metals and membrane electrode assembly for the Low Temperature Polymer Electrolyte Membrane (LTPEM) fuel cell sector. HyPlat is a specialist fuel cell technology company offering tailor-made MEA and catalyst products.
Manufacturing	Platinum powder nanomaterials	- 3D printing - New materials	- Lonmin	Development of a process to produce platinum powder to manufacture jewellery and medical and industrial products.
Manufacturing	Proto-type Fuel Cell Forklift and Hydrogen Refueling Station	- Energy storage - Hydrogen technologies	- Impala Refining Services - University of the Western Cape (HySA Systems)	Impala Refining Services (Implats) has funded HySA Systems R6 million towards the development of a fuel cell-powered prototype forklift and refueling station. The 3-tonne still forklift utilises a PEM (Proton Exchange Membrane) Fuel Cell and has been in operation since 2015.
Manufacturing	WeldCore® machine	- Diagnostic technologies	- Tectra Automation - Eskom SOC Holdings Limited - Nelson Mandela University	WeldCore utilises a specialised sampling technique to provide information on whether a pipeline or other high value component needs replacement.
Mining and quarrying	HYDRA Smart Mining	- Big data	- The Awareness Company (Pty) Ltd	HYDRA is a software solution that uses data aggregation and fusion technologies to enable digitalisation and create connected digital mines.
Mining and quarrying	Monster sensor	- Sensor technologies	- Centre for Scientific and Industrial Research (CSIR)	Prototype thermal imaging sensor used to detect loose rocks. In 2018, the CSIR Monster prototype was trialed using slope simulation.

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Mining and quarrying	Rock Pulse	- Sensor technologies	- Centre for Scientific and Industrial Research (CSIR)	Device that detects imminent mine roof collapses. Unveiled in 2018, the CSIR has supplied 10 prototypes of a device that detects and provides early warnings of goafs – a dangerous event that sees the underground roof in coal mines collapse – to a mining house in the South African coal mining industry.
Mining and quarrying	Rotowinner	- Processing technologies	- Free Radical Process Design (FRPD) - Technology Innovation Agency	Rotowinners are rotating stainless steel cylinders used to extract minerals from mining wastewater. The design is enhanced to accommodate the extraction of by-product minerals. The technology is currently being tested at Impala Refineries.
Transport and storage	MALII Smart mobility platform	- E-commerce - Mobile banking/ mobile money	- MALII Fintech - SAB Foundation - Rand Merchant Investments	MALII is an app that enables taxi commuters to make payments without using cash. Currently being piloted in Gauteng province with plans to scale nationwide. Addresses the cash payment system, financial exclusion, and inefficiencies in the minibus taxi industry.
Water supply, sewerage and waste management	Acid mine water treatment	- Water purification	- Roc Water Technologies (PTY) - Climate Innovation Centre South Africa - Water Research Commission	Roc Water Technologies has developed a unique, low-cost solution to produce drinking water and other valuable products from acid mine water. In 2019, the company raised R2.7 million from the Water Research Commission to demonstrate the technology at scale.
Water supply, sewerage and waste management	Water purification microfilter	- New materials - Water purification	- VulAmanz Water Filters - Technology Innovation Agency	Water purification microfilter that utilises a locally produced woven polyester microfiltration membrane. Currently seeking to pilot at scale.

Table 5.411: Emerging technologies in the adoption/ diffusion stage per sector of application

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Agriculture, forestry and fishing	Abalobi app	- Mobile applications	- Abalobi ICT4 Fisheries	Abalobi is a mobile app suite and non-profit programme. The Abalobi app is currently used by small-scale fishers along the South African coast and will soon be introduced to small-scale fishers in the Seychelles.
Agriculture, forestry and fishing	Aeroview platform	- Artificial intelligence - Drones - Mobile technologies	- Aerobotics - Naspers Foundry	Planning, monitoring and control centre for farmers. Using aeronautics and machine learning technologies to process aerial imagery and identify problems. Founded in 2014, Aerobotics is currently operating in 18 countries.
Agriculture, forestry and fishing	AgriKool crowdfunding	- E-commerce	- AgriKool	Providing smallholder farmers with finance and market linkage opportunities through its digital platform. Farmers are offered affordable, efficient and reliable options, and are linked to a network of informal vendors and supermarkets to sell their fresh produce.
Agriculture, forestry and fishing	Animal diagnostics services	- Diagnostic technologies	- Centre for Scientific and Industrial Research (CSIR) - Technology Innovation Agency - TokaBio (Pty) Ltd	4IR-enabled point-of-care diagnostics can diagnose foot-and-mouth disease in the field where livestock are kept, including remote locations.
Agriculture, forestry and fishing	Commercial drone spraying	- Drones	- PACSys (Pty) Ltd - DC Geomatics (Pty) Ltd	A joint venture between PACSys and DC Geomatics JV became the first SACAA-approved commercial drone spraying operation in 2019. In 2020, the venture had acquired 60% market share.
Agriculture, forestry and fishing	Controlled Environment Agriculture	- Automation software - Hydroponics	- AgriLED	AgriLED uses Controlled Environment Agriculture (CEA) within shipping containers to produce high-quality crops with great nutritional value using LED Grow Lamps. Founded in 2018, the company received funding from Hivos Impact Investments in 2019 to facilitate expansion.

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Agriculture, forestry and fishing	Khepri Meal™ and Khepri FF™	- Biotechnology	- Khepri Innovations - Technology Innovation Agency - SAB Foundation	Khepri FF™ is de-hydrated larvae supplied in bulk to the pet food industry and small organic farmers. Khepri Meal™ consists of highly nutritious dried defatted larvae that are ground into a high protein meal.
Agriculture, forestry and fishing	Khula Inputs App, Funder Dashboard and Fresh Product Marketplace	- E-commerce - Mobile applications	- Khula App (Pty) Ltd - AECI Ltd - E-Squared Investments	Khula provides small-scale and commercial size farmers with a software, product marketplace, and institutional funding platform. Launched in 2019, the company has signed up more than 3,000 farmers, and over 100 suppliers now work with the company.
Agriculture, forestry and fishing	SwiftVEE Mobile App	- E-commerce - Mobile applications	- SwiftVEE - Google Launchpad - Subtropico Limited	Online auction platform enabling the buying and selling livestock products where farmers can register and can make bids online or watch live online auction video streams. Developed by start-up SwiftVEE which was founded in 2017. Currently the largest independent livestock trading platform.
Electricity, gas, steam and air	Molten Salt Thermal Energy Storage Systems	- Energy storage	- Industrial Development Corporation - Engie SA - ACWA Power Solafrica Bokpoort - CSP Power Plant (Pty) Ltd - SENER - Acciona	Molten salts employed as a thermal energy storage to retain thermal energy. Component of solar energy systems for electricity generation. Deployed at several CSP plants in South Africa including Kathu Solar Park, Bokpoort Concentrated Solar Plant, Rooipunt Molten Salt Thermal Energy Storage System and Kalkaar Molten Salt Thermal Energy Storage System.
Electricity, gas, steam and air	Tokenized microgrids	- Blockchain - Microgrids	- Cenfura - DNA Global Energy	Microgrids tokenized using blockchain technology for community applications. One microgrid is in operation in South Africa, with 14 due to be rolled out (announced 2021).
Financial and insurance activities	Point of sale card machines	- E-commerce - Mobile banking/ money	- Yoco Technologies - Dragoneer Investment Group	Point of sale applications, payment gateway and card machines providing access to offline and online payments for small and independent businesses. Yoco was founded in 2013 and has raised $102 million in financing since inception.
Financial and insurance activities	ASIP Accelerator Program	- Financial technologies	- Startupbootcamp AfriTech - Telecel Group - Amazon Web Services - Délégation générale à l'Entrepreneuriat Rapide, Senegal	Cape Town-based multi-corporate-backed pan-African start-up accelerator launched in 2017. Provides access to a global network of corporate partners, investors, and mentors.
Financial and insurance activities	Digital escrow platform	- Mobile banking/ mobile money	- TruZo - UK-South Africa Tech Hub	TruZo, a digital escrow platform, act as a trusted third-party payment provider to both buyers and sellers of online and real-world transactions.
Human health and social work	Altis Osteogenic Bone Matrix	- Biotechnology - Medical devices - New materials	- Altis Biologics	Injectable bone morphogenetic proteins capable of inducing new bone formation commencing shortly after implantation into human recipients.
Human health and social work	Genetic testing service	- E-commerce	- Gknowmix - South African Medical Research Council	Integrated system for genetic testing service delivery involving healthcare practitioners, medical scientists, laboratories and the public. Gknowmix was founded in 2007 as a spin-off company from the South African Medical Research Council.
Human health and social work	TeleSensi™ Cardiac	- Artificial Intelligence - Diagnostic technologies	- TeleSensi	An AI-powered murmur screening service. Available as a stand-alone product or integrated with TeleSensi™, a cloud-based telehealth service with integrated stethoscope streaming, user management and auscultation guide
Human health and social work	X-ray imaging devices	- Biomedical imaging	- Lodox Systems - Industrial Development Corporation - Technology Innovation Agency	Lodox Systems produces full body X-ray imaging devices for medical use in trauma and forensic pathology centres using ultra-low X-ray doses for frequent and rapid scanning. The Industrial Development Corporation (IDC) of South Africa is the major shareholder of Lodox Systems. The Technology Innovation Agency has committed funding for the development of Lodox's next generation X-ray machines.
Information and communication	AI models to predict consumer behaviour	- Artificial intelligence - Big data	- Xineoh	Application Programming Interface (API) platform enabling the prediction of customer behaviour using artificial intelligence. South African start-up headquartered in the US with operational headquarters in South Africa.

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Information and communication	FibrePoynt	- Wireless technologies	- Technology Innovation Agency - Poynting Group	FibrePoynt technology uses passive beam forming, beam pattern diversity and beam shaping to get the best possible signal to the home units which then provides Wi-Fi for the end user devices to connect to. Offers alternative deployment of broadband infrastructure. Development was funded by the Technology Innovation Agency.
Information and communication	One-way video interview software	- Automation software	- Wamly (Pty) Ltd - Knife Capital	Software that helps companies recruit people for vacant positions without the need for one-on-one interviews, allowing them to interview more people and better candidates, faster. Wamly has established itself as the biggest such provider in Africa. Funding received from Knife Capital in 2022 to support product
Information and communication	Virtual advisors	- Artificial intelligence - Automation software	- CLEVVA (Pty) Ltd - Blue Prism Ltd	Artificial Intelligence-powered virtual advisors, used to train and guide sales representatives. CLEVVA has partnered with UK-based robotic process automation (RPA) firm Blue Prism to automate front-office sales and support journeys across staff-assisted and self-service.
Manufacturing	Autonomous electric vehicle (EV) assembly line	- Artificial intelligence - Industrial robots	- Jendamark	Autonomous electric vehicle (EV) assembly lines commissioned by a Silicon Valley startup, in California. Jendamark is a South African firm that offers turnkey production solutions. The project was completed in 2020.
Transport and storage	Electric cargo vehicles	- E-commerce - Energy storage	- Mellowcabs	Light electric cargo vehicles providing low cost, efficient and emission-free delivery services in cities. Offers bespoke client-specific offerings like active cooling and security features
Electricity, gas, steam and air	Lithium-ion batteries	- Energy storage	- I-G3N - Edge Growth - ASISA ESD	Production of Lithium Phosphate batteries for stationary storage in conjunction with solar PV.

SECTOR	TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Transport and storage	uYilo eMobility Programme	- E-commerce - Energy storage	- Nelson Mandela University - Global Sustainable Mobility Partnership - Technology Innovation Agency	The national uYilo Electric Mobility Programme was established in 2013 as an initiative of the Technology Innovation Agency to enable, facilitate and mobilise electric mobility. Services include the uYilo 'Kick Start' fund was established to support local industry related projects that can be commercialised to advance localisation of the South African eMobility industry.
Transport and storage	Lula mobility platform	- E-commerce - Mobile application	- Lula Loop (Pty) Ltd	Mobility platform that provides a transport service for businesses and private clients, connecting corporate commuters to safe, affordable, and sustainable shuttles.
Water supply, sewerage and waste management	Nanotech water filtration and treatment	- Nanotechnologies	- Kusini Water - Vumela Fund	Water filtration and treatment systems using nanotechnology, food processing waste (macadamia shells) and equipped with Internet of Things technology. Kusini Water was founded in 2017 and secured undisclosed funding from Vumela Fund, announced 1 December 2021

ANNEX 6: Risks of Emerging Technologies

RISKS RELATED TO EMERGING TECHNOLOGIES

RISK TO JOBS

South Africa has an unemployment rate of 35.3%. Therefore, emerging technologies are generally feared for their potential to further increase the rate of unemployment. According to DST (2019), rapid technological changes may put traditional jobs at risk while increasing the mobility of highly educated individuals, supported by technology, increasing competition and the risk of skills loss. Technological progress may exacerbate the mismatch of skills requiring additional training and education to ensure employment. In their paper about the rise of AI and robots, Rapanyane and Sethole (2020) stress the negative impact that these technologies will have on the jobs, as they believe that machines and robots are more likely to replace humans in the workplace.

South Africa consists of a few sectors that are labour intensive such as manufacturing, mining and construction. These contribute immensely to the GDP of the country. Although beneficial, the use of 4IR technologies in these sectors is likely to have a negative impact on the jobs of many South Africans. In the manufacturing sector for example, automation and digitisation may reduce the cost of manufacturing according to Serumaga-Zake and van der Poll (2021). Serumaga-Zake and van der Poll (2021) further explain that the reduction in manufacturing costs will result in the export of assembly operations (such as in the automotive industry) back to developed countries, as low cost labour will no longer be an effective strategy. This will impact negatively on jobs in those industries. In the mining sector, although there is an agreement that 4IR technologies will bring about safer and more effective production, Mutanga, Hongoro, Kaggwa, Chavalala, Pitso, Mohlala, Siame, Sichilima and Tshililo (2021) deduced that the use of 4IR technologies will have a negative impact on jobs in South Africa. Citing changes such as autonomous equipment, digital capturing of information and drones, Mutanga et al. (2021) state that in a situation where 10 people would be employed, only one will be, thereby stressing the negative impact of 4IR technologies on the employment of miners. In the construction sector, although 4IR technologies are recognised for their ability to resolve health and safety issues, Malomane, Musonda and Okoro (2022) found that fear of job losses ranked second only to finances, when analysing the challenges concerned with the adoption of 4IR technology in the sector.

Magwentshu, Rajagopaul, Chui and Singh (2019) specifically address the impact of digitisation on productivity and job creation in their report. The report highlights that occupations with low mobility may face higher risks of displacement, requiring deeper, targeted interventions. Failure to reskill and upskill or to incorrectly anticipate long-term technology impacts may also constrain productivity and employment growth (Magwentshu et al., 2019).

RISKS TO THE PLANET

The introduction of some 4IR technologies pose risks to the ecology and the environment. UNIDO (2019) note that many 4IR technologies require rare minerals and significant levels of energy and as such negate the benefits of these technologies. This is particularly the case if mining of minerals occurs without adequate regulation and energy is produced using predominately fossil fuels.

Drones in the fishing industry is one such technology. According to Winkler, Butler, Attwood, Mann and Potts (2022), Drone fishing has become popular in the recreational fishing community as drones transport baited lines into inaccessible areas or can be used to identify optimal fishing areas and essential fish habitat. However, this poses a risk to the ecology with a decline in fish population (Winkler, Butler, Attwood, Mann and Potts, 2022). It appears that drone fishing creates an over-exploitation of many fish species targeted, while the released fish are vulnerable to heightened stress and mortality (Winkler, Butler, Attwood, Mann and Potts, 2022). Moreover, the species targeted by recreational drone fishers are also targeted by small-scale fishers that fish for food security and livelihood. Therefore, drone fishing poses a risk to the livelihoods of these small-scale fishers.

RISKS TO HUMAN HEALTH

Safodien (2021) explored the role of social work in the digital revolution, specifically the migration of social work from face- to- face interactions to online. He noted that there are ethical risks in performing social work online that include data capturing on data management systems. Social workers are concerned about access to client data which is highly confidential. In other words, cybersecurity is a risk associated with the employment of emerging technologies. Cybersecurity not only affects this area but various others. Dette (2018) pointed out that inadequate digital security can increase the risks of digital attacks, while increasing amounts of digitised data increase the risks of data abuse.

Rapid technological innovation, dependence on electronic equipment, and reduced lifespan of electronic and electrical products are key factors contributing to the accelerated production of e-waste. This phenomenon increasingly impacts developing countries like South Africa, demanding policies to support sustainable e-waste management (Borthakur, 2020). A study of mixed stream waste in three South African landfills found that adjacent communities may be susceptible to risks of cancer, mutagens and congenital disabilities arising from heavy metals and compounds associated with e-waste in unregulated landfills (Machete, 2017).

While many emerging technologies offer solutions to critical societal challenges, they may also demand new control mechanisms to address the risks and hazards of new production processes where regulations and standards have not yet been introduced. For example, additive manufacturing processes may expose workers to allergic asthmagens, and mucous membrane and respiratory irritants hazards to human health (Du Preez et al., 2018).

RISK OF INCREASING INEQUALITY

South Africa has one of the highest levels of inequality in the world, with a Gini coefficient of 0.63. Therefore, inequality in the country is a serious matter and it is important to consider the impact of 4IR technologies on inequality. Digital technologies have the potential to deepen inequalities as new tools risk entrenching power dynamics (Dette, 2018). In the literature, it is further noted that some authors are of the opinion that 4IR technologies have the potential to further increase the inequalities present in South Africa while others offer a contrasting opinion. Selelo and Khwela (2022) argue that 4IR technologies are advocated by large companies to increase their production because they are well-resourced, to the detriment of small businesses. However, they recommend support to SMEs, in the form of finance and skills development, so they may also partake in the digital revolution. Menon and Fink (2019) also believe that the 4IR has the potential to bring more inequality within a country, in the sense that it may promote non-inclusiveness. They therefore recommend policy changes that are inclusive, open and agile.

Gender-based inequalities are also considered in the literature. The DST (2019) White Paper singles out the negative impact of technologies such as AI, with risks that perpetuate gender bias through its incorporation into AI applications.

The following table summarises general risks with the focus on key references.

EMERGING TECHNOLOGY	SUMMARY OF GENERAL RISKS	KEY REFERENCE
Digital risks	This report examines digital technology risks in humanitarian contexts, while providing insights as to how these risks could manifest in other settings. Chiefly, inadequate digital security can increase the risks of digital attacks, while increasing amounts of digitised data increase the risks of data abuse. Digital technologies may also serve to deepen inequalities as new tools risk entrenching power dynamics. In humanitarian contexts, technology may increase dependency on new actors who may compromise the values and objectives of existing actors.	Dette (2018)
4IR	Rapid technological changes may put traditional jobs at risk while increased mobility of highly educated individuals, supported by technology, increases competition and the risk of skills loss. Technological progress may exacerbate the mismatch of skills requiring additional training and education to ensure employment. The white paper also singles out the negative impacts of AI such as the risk of perpetuating gender bias through its incorporation into AI applications, thus stifling economic growth. The blurring of digital and physical boundaries suggests important ethical, legal and socio-economic consequences, as 4IR impacts all facets of human life.	DST (2019)
4IR	This report presents the results of 100 South African respondents to a global survey of C-suite executives on 4IR. Responses indicated that South African executives are cognisant of the impact on the workforce and the need to rethink the social/ labour contract, amongst others.	Deloitte (2018)
4IR	This report discusses the implications of 4IR on higher education and training, in the context of the risks and opportunities that these technologies present. Key risks stemming from 4IR that may potentially exacerbate inequality, thus warranting a response, include the potential for exclusion from the workforce, the risk of dependence on technology, the financial implication of institutions harnessing ICT, the need for stable electricity connections, and access to hardware and broadband.	DHET (2021)
IT	This report presents cyber security risks in the South African landscape (including recent examples) such as mobile banking and credit card fraud, hacking and data theft, DDoS attacks, ransomware and shadow IT, and using devices to mine cryptocurrency.	Mcanyana, Brindley and Seedat (2020)
Digitisation	This report specifically addresses the impact of digitisation on productivity and job creation. The report highlights that occupations with low-mobility may face higher risks of displacement, requiring deeper, targeted interventions. Failure to reskill and upskill or to take incorrectly anticipate long-term technology impacts may also constrain productivity and employment growth.	Magwentshu et al. (2020)
Unmanned vehicles - drones	Drone fishing creates an over-exploitation of many fish species targeted while the released fishes are vulnerable to heightened stress and mortality. The species targeted by recreational drone fishers are also targeted by small-scale fishers that fish for food security and livelihood.	Winkler, A.C., Butler, E.C., Attwood, C.G., Mann, B.Q. and Potts, W.M., 2022.
Computer based social work – The use of online data capturing management systems	Although the use of data management systems in social work was found to be beneficial, risks were identified including concerns over access to client data on the systems, which is highly confidential.	Safodien, 2021
4IR technologies in the manufacturing sector	Automation and digitisation in the manufacturing sector may reduce cost of manufacturing, resulting in the export of assembly operations back to developed countries as low-cost labour will no longer be an effective strategy for foreign investors.	Serumaga-Zake and van der Poll, 2021
4IR technologies in the mining sector	Changes brought by 4IR technologies, such as autonomous equipment, digital capturing of information and drones will result in loss of jobs in the mining sector. Mutanga et al. (2021) state that in a situation where 10 people would be employed, only one will be.	Mutanga, Hongoro, Kaggwa, Chavalala, Pitso, Mohlala, Siame, Sichilima and Tshililo (2021)
4IR technologies in the construction sector	It was found that fear of job losses ranked second only to finances in this sector.	Malomane, Musonda and Okoro (2022)

RISKS RELATED TO THE TOP EMERGING TECHNOLOGIES IN SOUTH AFRICA

The top 20 emerging technologies were identified in Table 2 of this report. Below we provide an overview of the risks identified in the literature, predominately specific to South Africa, for the top five technologies listed in Table 2: e-Commerce, 3D printing, new hydrogen technologies, AI, energy storage, software/ mobile, biotech, next generation medicine.

E-COMMERCE

The risks and harms associated with e-commerce are well elucidated in the South African context. More broadly speaking, e-commerce is vulnerable to many of the risks associated with information and communication technology in general. Risks identified include vulnerability to hacking and data theft, DDoS attacks, ransomware and shadow IT, and the stealth use of devices to mine cryptocurrency, partly attributable to poor public knowledge of cyber threats (Mcanyana, Brindley and Seedat, 2020). Mobile and mobile banking and credit card fraud are also primary concerns for consumers, while the perceived risk of financial losses is likely the most impactful inhibitor of online shopping (Malapane, 2019). There are also concerns about product safety and language accessibility of contractual agreements and technical specifications reflecting South Africa's diversity and 11 official languages (Mkhosi, 2017). Online vendors, in turn, are faced with additional business risks, including exposure to exchange rate volatility (when trading internationally), high transaction costs, poor infrastructure, and reliance on private courier services (Goga, Paelo and Nyamwena, 2019).

The key references for risks associated with e-commerce are tabulated below.

KEY REFERENCE	SUMMARY OF KEY RISKS
Malapane (2019)	This study finds that the perceived risk of financial losses is the most impactful on online shoppers, followed by data corruption. Data exposure along with denial of service are also significant. The study also found that confidence in online shopping is above average relative to other industries, bar privacy issues.
Goga (2021)	Although South Africa has widespread ICT coverage, the relatively high cost of data coupled with access to smartphones are likely inhibiting the uptake of e-commerce technologies and the role that these technologies could play in facilitating inclusive development.
Goga, Paelo and Nyamwena (2019)	Banking and transaction fees may be particularly onerous for small businesses accessing third-party marketplaces as sales channels. Businesses who transact internationally also face additional onerous costs, coupled with risk exposure to exchange rate volatility. Improved customer awareness and literacy is required to mitigate risks pertaining to customer information protection and fraud.
Mkhosi (2017)	This report argues that general challenges facing small and medium enterprises in South Africa are necessarily linked to e-commerce uptake. These include access to finance and credit, poor infrastructure, lack of access to markets, reliance on costly private courier services. The author recommends policy interventions that address risks pertaining to payment protection, product safety and language accessibility for contractual and technical information.

3D PRINTING

Risks associated with 3D printing can be considered at both the technological level and within the specific context of its application. At the broader technological level, the lack of standardisation has been raised as a key concern in the South African context (Alabi et al., 2020). Lack of standardisation impedes technology adoption and diffusion, impacting the consistency, reliability and quality of products in end-use applications (de Beer et al., 2016). Risk of exposure to airborne contaminants emanating from printing and post-printing processes can also be of concern, requiring new or improved control technologies (Du Preez et al., 2018). While novel applications of 3D printing are advancing, literature thus far offers better clarity on benefits as opposed to risks and harms in specific applications in the South African context (e.g. ASSAf, 2021; de Beer et al., 2016). As discussed in Case study 2: 3D printing in South Africa, several applications are being explored in various sectors, such as construction, aviation and health. Here application-specific risks emerge. For example, ethical and regulatory risks arise in biomedical applications such as tissue printing, while ease of customisation, public accessibility and patient-specific necessities are also vital (Fanucci, Barwick and Prinsloo, 2019). Issues of quality and integrity are also paramount in the building and construction industry, where products need to meet the National Building Regulations (ASSAf, 2021).

The key references for risks associated with 3D printing are tabulated below.

KEY REFERENCE	SUMMARY OF KEY RISKS
Paul et al. (2018)	This study draws on international experience, collating key challenges facing the implementation of 3D printing technologies in the building and construction (B&C) industry. These include the large scale of objects required for B&C, conservatism in B&C industries, and strict controls enforced by standards and governing bodies.
Alabi et al. (2020)	This study considers risks and challenges from the perspective of additive manufacturing education. Lack of standardisation inhibits additive manufacturing technology progress. Standardisation, in turn, requires adequate and effective research and development. The authors also identify funding as an important enabler of additive manufacturing research.
Blakely-Milner et al. (2021)	In a comprehensive review of the literature on additive manufacturing in the aerospace sector the authors find that a major challenge is the lack of technological standards and approaches to certification due to the rapid growth of the technology in last decade. This challenge, in turn, is compounded by issues of traceability in the AM process, and the lack of data regarding failure mechanisms, amongst others.
Du Preez et al. (2018)	Exposure to volatile organic compounds which are respiratory and mucous membrane irritants or allergic asthmagens can negatively impact worker health. Both printing and post-printing processes should be evaluated to implement appropriate control technologies.
Fanucci, Barwick and Prinsloo (2019)	This study examines the prospects and challenges of bioprinting in South African clinical environments. Application-specific risks to technology uptake include ethical and regulatory issues, the need for more efficient commercial bio printers and the complexity of biomedical applications. Ease of customisation, public accessibility and patient-specific necessities are also mentioned.

NEW HYDROGEN TECHNOLOGIES

Hydrogen and related technologies associated with usage have progressed considerably in the last decade. However, ongoing research and development remain vital to address critical issues regarding safety and security across the value chain, including in production, transportation, storage and usage (DSI, 2001; GIZ, 2017). Consequently, regulatory reform is critical to establishing standards and regulations (DSI, 2021). From a socio-economic perspective, the government is advancing South Africa's hydrogen economy to drive inclusive economic growth and development. The government's position is that these technologies have the potential to address critical challenges pertaining not only to climate change and the environment but also to address income and wealth disparity and high levels of unemployment. Cognisant that transitions may exacerbate socio-economic challenges and further entrench power imbalances, implementation of the national strategy includes the development of a just transition framework. Mirroring many developing countries, South Africa also has limited gas infrastructure, which needs to be developed. Pursuing and promoting the usage of grey and blue hydrogen, in anticipation of green hydrogen achieving cost parity, is a key strategic objective (DSI, 2021) with potentially adverse environmental impacts. Commitment to infrastructure also carries risks without adequate uptake of this renewable energy.

The key references for risks associated with new hydrogen technologies are tabulated below.

KEY REFERENCE	SUMMARY OF KEY RISKS
DSI (2021)	South Africa's Hydrogen Society Roadmap provides an overview of risk, challenges and opportunities identified through a comprehensive stakeholder engagement process. Safety and security, land rehabilitation after hydrogen storage and environmental impacts are risks that need to be addressed through rules, regulations and standards.
Sadik-Zada (2021)	Adopting a global perspective, this author highlights that green hydrogen remains cost prohibitive compared to other green and fossil-based technologies, restraining renewable energy transitions. Countries that are least developed will require significant investment into electrolyser capacity coupled with increased renewable energy generation. Additional issues facing developing countries include insufficient human capital to develop a hydrogen economy and the lack of non-renewable hydrogen infrastructure to leverage infrastructure complementarity.
GIZ (2017)	This report provides an overview of hydrogen research and development in South Africa. Hydrogen research and development is driven primarily by the South African government and academic institutions. Barriers to technology development relate primarily to funding. Notable risks which R&D needs to address includes high-density energy storage at ambient conditions, fire and explosion protection and hydrogen transportation.
DSI (2021)	The South African national hydrogen road map highlights several risks pertaining to hydrogen and related technologies. Chiefly, safety and security relating to both production and use of hydrogen, necessitating significant regulatory reform. Given South Africa's socio-economic challenges, including significant income and wealth inequality and low levels of employment, developing a just transition framework to mitigate social harms is central to the road map's implementation, although the mechanisms relate primarily to job creation. The need to promote grey and blue hydrogen uptake as pathways to a green hydrogen transition also has environmental implications.

SOFTWARE/ MOBILE

Although based in the USA, Veracode (an application security company) published a document where the top 10 risks associated with software and mobile applications are identified. These vary from malicious functionality to vulnerabilities of software and mobile applications. A few are relevant to South Africa and are discussed next.

a) **Activity monitoring and data retrieval** – Stored data such as contact lists, saved email and messages can be retrieved for malicious purposes. However, the Cybersecurity Act addresses this risk under Part 11 – Malicious communication. This section of the Act discusses the retrieval and disclosure of such information and declares it a criminal offence.

b) **Unauthorised network connectivity** – Unauthorised data transfer from one's computer can take place through unauthorised connectivity using software tools. This is referred to in the Act as data interception and is defined as "the acquisition, viewing, capturing or copying of data of a non-public nature through the use of a hardware or software tool". The Act declares such as a criminal offence.

c) **Impersonation** – This is said to be similar to phishing attacks that impersonate bank websites, for example. In this case the user is asked to authenticate, thereby sending their credentials such as passwords, to the impersonator. This too is addressed in the Cybersecurity Acts under the "Unlawful acquisition, possession, provision, receipt or use of password, access code or similar data or device" section of the Act. South Africa banks, such as ABSA, have also mitigated this risk through communication with their clients, informing them of the kind of information they will not ask of them.

d) **Sensitive data leakage** – It is stated in the Veracode report that it is possible for a legitimate app to be poorly designed and in that way, leak sensitive data such as your location to third parties.

e) **Unsafe sensitive data storage and transmission** – The same report states that mobile apps store sensitive data such as passwords, credit card numbers and payment system pin numbers. However, if these are not encrypted, the user is exposed. Furthermore, through the use of unsafe public Wi-Fi, unencrypted data can be accessed by attackers

The key report that focuses on the risks associated with software/ mobile applications is tabulated below:

KEY REFERENCE	SUMMARY OF KEY RISKS
Veracode (2010). The Mobile App Top 10 Risks.	This report lists the top 10 risks associated with software/ mobile applications including sensitive data leakage, storage and transmission.

BIOTECHNOLOGY

Both the academic and grey literature reviewed identify the need for pharmacovigilance to ensure that people are safe from the emerging technologies. Although the literature is not South Africa-specific, it points to the need for structures to monitor the products coming into the market to be built into the emerging technologies and products from inception to deployment. Most of the literature is based on the guidelines of the United States Protection Agency and endorses a process like Safe-by-Design, and others. The article by Xue et al. (2021) for example recognises the threat that although emerging biotechnology products bring great benefits to human health and welfare, the potential threat of their use for development of biological weapons or bioterrorism cannot be ignored. Zoe (2018) suggests that the Safe-by-Design approach is a most useful method of ensuring safe biotech products. Similarly, The Future Life article acknowledges that the same biotech products that are being used to extend our lives could as well be used to end it. The article provides an example of engineering super-flu viruses which may cause a decrease in public trust of biotech products.

The key reports that focus on the risks associated with biotechnology are tabulated below:

KEY REFERENCE	SUMMARY OF KEY RISKS
US Environmental Protection Agency (2013) Next generation Risk Assessment Incorporation of Recent Advances in Medicine, Computational and Systems Biology. National Center for Environmental Assessment	This report describes the NexGen programme, a multi-year, multi-organisation effort to develop and evaluate new molecular, computational, and systems biology informed approaches to risk assessment. The goal of this effort is to advance risk assessment by facilitating faster, less expensive, and more robust assessments of public health risks by the EPA's Office of Research and Development. The specific aims of the programme are to: • demonstrate proof of concept that recent advances in biology can better inform risk assessment; • understand what information is most useful for particular purposes (value of information); • articulate decision rules for use of new types of data and methods to inform risk assessment; and • identify important data gaps.
Xue, Y.; Yu, H.; Qin, G. 2012. Towards Good Governance on Dual-Use Biotechnology for Global Sustainable Development. Sustainability 2021, 13, 14056. https:// doi. org/10.3390/su132414056	This study acknowledges that new dual-use biotechnology, represented by gene editing, synthetic biology, and gene driving, has brought great benefits to human health and welfare, but may also be used for the development of biological weapons or bioterrorism. The international community recognises the potential social and economic benefits of dual-use biotechnology, but it is difficult to prevent this technology from being misused or abused. If left unchecked, these may destroy human living conditions and social order. The report contends that despite the benefits of dual-use technology, good governance is needed to mitigate its risks. It argues that governance of the dual-use risks of biotechnology should avoid the traditional bottom-up or top-down modes and instead follow the four-stage experimentalist governance model. The first stage is to achieve consensus on a broad governance framework with open-ended principles. The second stage is for countries to take action based on local conditions and the open-ended framework. The third stage is to establish a dynamic consultation mechanism for transnational information sharing and action review. The fourth and final stage is to evaluate and revise the global governance framework
Robaey, Zoë. 2018. Dealing with risks of biotechnology: understanding the potential of Safe-by-Design. Report commissioned by the Dutch Ministry of Infrastructure and Water Management.	This report provides a summary of recent advances in biotechnology with regard to Safe-This report provides a summary of recent advances in biotechnology with regard to Safe-by-Design, a new way to deal with the risks of biotechnology. The report recognises that rapid developments in biotechnology are possible with techniques that enable doing genetic engineering faster and with more precision. These developments create new opportunities to eradicate diseases, breed healthier livestock and clean soils. As questions on new risks of biotechnology follow these new opportunities this report investigates and explains the opportunities and challenges offered by the concept of Safe-by-Design to manage risks. Safe-by-Design options minimise or prevent risks that are defined early on and integrated into the design of a technology. This brings assessing and managing risks closer through iterative design loops. In addition to being a risk management strategy, Safe-by-Design can enable design with safety as a design goal. Safety can be understood as the absence of unacceptable risks, but safety is also a public value, which involves the perception of safety by different stakeholders. Therefore, different experts and stakeholders may be involved in every iteration, by identifying risks and defining what is necessary for safety.

KEY REFERENCE	SUMMARY OF KEY RISKS
https://futureoflife.org/background/benefits-risks-biotechnology/	The article on this website suggests that rewriting the blueprints of life, as done by biotechnology, carries an enormous risk. To begin with, the same technology used to extend our lives could instead be used to end them. While researchers might see the engineering of a supercharged 'flu virus as a reasonable way to better understand and thus fight the 'flu, the public might see the drawbacks as equally obvious: the virus could escape, or someone could weaponise the research. The advanced genetic tools that some are considering for mosquito control could also have unforeseen effects, possibly leading to environmental damage.
National Academies of Science. 2017. Preparing for Future products of Biotechnology. https://www.ncbi.nlm.nih.gov/books/NBK442208/	This book deals comprehensively with the risks associated with current and future biotechnology and concludes that: • The scale, scope, complexity, and tempo of biotechnology products are likely to increase in the next 5-10 years. Many products will be similar to existing biotechnology products, but they may be created through new processes, and some products may be wholly unlike products that exist today. • The current biotechnology regulatory system is complex and fragmented, and can be difficult for individuals, nontraditional organisations, and small- and medium-sized enterprises to navigate. This might cause uncertainty and a lack of predictability for the developers of future biotechnology products, and has the potential for a loss of public confidence in their regulation. • The risk assessment endpoints for future biotechnology products are not new compared with those of existing biotechnology products, but the pathways to those endpoints have the potential to be very different in terms of complexity.

NEXT GENERATION HEALTH

Both the academic and grey literature endorse the monitoring of next generation health using the pharmacovigilance system. The World Health Organization defines pharmacovigilance as: "the science and activities relating to the detection, assessment, understanding and prevention of adverse effects or any other drug-related problem".

Essentially, it is drug safety. Pharmacovigilance ensures the rigorous testing of clinical drugs to improve patient care and reduce the risk of negative side effects. Present throughout the drug lifecycle, PV certifies whether a drug works and if it is safe to use. Bate and Stegmann (2012) argue for harnessing the benefits of the Pharmacovigilance System. They advocate for automation as enabled by big data and argue that it is crucial to involve patients in the whole process. Menard et al. (2021) propose next generation sequencing (NGS) be integrated into clinical drug development as it makes it easier to identify patients who would benefit from particular therapies. Trifirò and Crisafulli (2022) outline challenges and opportunities of pharmacovigilance, as occasioned by the COVID-19 pandemic. They point out how innovative therapeutics, such as advanced therapy medicinal products, digital therapeutics and vaccines based on advanced technologies, requiring special pharmacovigilance monitoring, have been increasingly marketed in recent years, often upon accelerated pathway approval. Fast acceleration may portend a potential risk as long-term studies on the efficacy of such drugs are often missing.

The key references for risks associated with next generation medicine are tabulated below.

KEY REFERENCE	SUMMARY OF KEY RISKS
Bate A and Stegmann J. 2021. Safety of Medicines and Vaccines: Building Next-Generation Capability. Trends in Pharmacological Sciences. Vol 42 (12). Pp 1051 – 1061 https://doi.org/10.1016/j.tips.2021.09.007.	The article acknowledges that while the most significant advances in medicine developments have occurred over the past 50 years, the extent to which some of these advances have positively impacted the capability for ensuring patient safety is questionable. The article reviews how the conduct of safety surveillance has changed, highlights recent scientific advances, and argues how they need to be harnessed to enhance pharmacovigilance in the future. Specifically, the authors describe five changes that need to happen globally in the coming years: • better, more diverse data used for safety; • the switch from manual activities to automation; • removal of limited value, extraneous transactional activities and their replacement with a sharpened focus on scientific efforts to improve patient safety; • patient-involved and focussed safety; and • personalised safety.
https://allaboutpharmacovigilance.org/next-generation-drug-safety/	This article titled "Next-Generation Drug Safety" deals with the pharmacovigilance system, which is designed to enable people to benefit from medicines while making them as safe as possible by characterising, minimizing and preventing risks. The article opines that the pharmacovigilance process has made great progress moving from reactive to proactive monitoring activity based on careful planning before a product is placed onto the market.
Ménard, T., Barros, A. & Ganter, C. 2021. Clinical Quality Considerations when Using Next-Generation Sequencing (NGS) in Clinical Drug Development. *Ther Innov Regul* Sci 55, 1066–1074 (2021). https://doi.org/10.1007/s43441-021-00308-6	Next-generation sequencing (NGS) and decreased costs of genomic testing are changing the paradigm in precision medicine and continue to fuel innovation. Integration of NGS into clinical drug development has the potential to accelerate clinical trial conduct and ultimately shape the landscape of clinical care by making it easier to identify patients who would benefit from particular therapy(ies) and monitor treatment outcomes with less invasive tests. This research identifies existing and applicable regulations, guidelines and recommendations that could be translated into clinical quality considerations related to technology, data quality, patients and oversight. The research proposes these as a basis for pharmaceutical sponsors using NGS service providers in clinical drug development to develop a set of guidelines for NGS clinical quality.
Trifirò G and Crisafulli S (2022) A New Era of Pharmacovigilance: Future Challenges and Opportunities. *Front. Drug. Saf. Regul. Vol 2* doi: 10.3389/fdsfr.2022.866898	This article discusses challenges and opportunities in pharmacovigilance. It posits that in the field of drug safety and regulation, a number of challenges have to be faced in the near future. The COVID-19 pandemic highlighted the relevance of pharmacovigilance and proper risk communication during public health emergencies. Second, the development of advanced methodologies including machine learning techniques and the availability of large amounts of electronic healthcare data offer opportunities to optimise drug benefit-risk profile evaluation in real world settings. Finally, innovative therapeutics, such as advanced therapy medicinal products, digital therapeutics and vaccines developed based on advanced technologies requiring special pharmacovigilance monitoring have been increasingly marketed in recent years, often upon accelerated pathway approval.

ARTIFICIAL INTELLIGENCE

Concerns have been echoed about the possibilities of this expansive technology and are worth noting. In a 2021 interview, Elon Musk emphasized several risks imposed on humans with the application of AI. These include widening socioeconomic inequalities; massive threat of job loss around the globe as 36 million jobs can indefinitely be replaced by automated processes; AI bias on applications, criminal procedures, credit scores; and a threat to international peace and security with the looming threats of an AI arms race (Thomas, 2021).

Artificial intelligence has evolved tremendously from 1950 where Alan Turing questioned if machines can think, resulting in the development of the 'Turing Test' (Turing, 1950). The 'Turing Test' is an imitation game measuring performance between an intelligent machine and a human being and was considered a sufficient test for attributing thinking capacity to a machine. In his reflections, Turing acknowledged that the creator of the machine may not fully understand the extensive possibilities of his or her creation despite being able to make some prediction of its abilities.

While adoption of AI has been widespread, several barriers hinder adoption and implementation. Fu (2018) states that these include: a) the availability of data and significant amounts of missing or disparate data; for AI to operate at its optimum level, large and clean data sheets are significant; b) complexity challenges that pertain to the 'know-how' as each level of AI becomes more advanced and complex, we require high-levels of knowledge to improve and adopt AI systems; c) time and energy limitations where supportive hardware is required for the application and use of AI; and d) a skills gap which refers to the significant talent shortage in the AI industry.

The key references for risks associated with artificial intelligence are tabulated below.

KEY REFERENCE	SUMMARY OF KEY RISKS
Thomas, M. 2021. Built In: '7 Dangerous Risks of Artificial Intelligence'. Available online from https://builtin.com/artificial-intelligence/risks-of-artificial-intelligence	- Job automation, referring to the degree in which jobs will be replaced. Currently, 36 million people have jobs with a high exposure to automation. - Privacy, the threat to security and increasing rise of deepfakes. - AI bias - Widening socioeconomic inequalities - Potential AI arms race as powerful states attempt to acquire the most advanced autonomous weapons and threaten global in/security
European Parliament. 2022. News: 'Artificial intelligence: threats and opportunities'	Biases with unmanned AI processes and machinery are highly unlikely and may influence decisions based on gender, nationality, race, and age. These may be in various decision-making processes such as loans, criminal proceedings, and hiring or firing. The accountability and liability of AI is a relevant point of concern. If any action led by an AI-led machine inflicts risk or harm on a human, who is accountable for it? On the other end of the spectrum, the European Parliament asserts that the underuse of AI is also a dire threat as its lack of application may pose consequences for missed opportunities, poorer possibilities, poor infrastructure, lack of initiative and further low investment

ENERGY STORAGE

Energy storage products are becoming increasingly common, utilised every day for both public and private use. Lithium-ion batteries are widely used in the workplace due to their high power density and high energy (Hercegovac and Frangos, nd). Thermal runaways are possible if the limits of thermal stability have been exceeded, resulting in intense dispersion of smoke, heat, and toxic substances such as hydrogen fluoride (HF). The risks stem from the batteries overheating or overcharging and manufacturing or mechanical defects. Gottesfield (2019) states that the response to climate change has led to the widespread adoption of lithium-ion batteries, despite serious and notable concerns this poses for environmental health. Trafigura (2018) highlights that, at the time of writing, there were close to four million electric cars with lithium-ion batteries in use, with sales growing by 50% yearly, further contributing to environmental and health risks.

Killer, Farrokhseresht and Paterakis (2020) conducted an extensive study on the implementation of large-scale li-ion battery energy storage systems (BESS) within the European, Middle Eastern and African (EMEA) regions, finding little evidence of application despite large scale potential. In addition, these are easy to implement and occupy small spaces. This application may be further advanced and extended if there are postive technological advances, policy changes and cost reduction. Lastly, li-ion (BESS) can trigger shifts towards decentralisation of power generation. An synposis of li-ion (BESS) is provided below.

REQUIREMENTS	POTENTIAL

- Remote location
  • No available grid connection (or very expensive)
  • Inconvenient access (expensive fuel transportation)
- High diesel prices
- Need for sustainability
	- Big future market
	- Increasing gas prices
	- Increasing value of energy independence
	- EU roadmap for renewable sources on islands

RISK	**KEY DRIVERS**
- Microgrid complexity - Regulatory and legal framework	- Known revenues - Non-Monetised value

Source: *Off-grid microgrids – overview of the use (Killer, Farrokhseresht and Paterakis, 2020)*

KEY REFERENCE	SUMMARY OF KEY RISKS
Gottesfeld, P., 2019. Commentary health risks from climate fix: The downside of energy storage batteries, *Environmental Research, Volume 178, 108677, ISSN 0013-9351,* *https://doi.org/10.1016/j.envres.2019.108677.* (https://www.sciencedirect.com/science/article/pii/S0013935119304748)	Gottesfeld explored the risks associated with energy storage and reached several conclusions: - There is an escalating demand for energy storages due to climate change. - Battery power plants are highly polluting. - Due to exorbitant costs and technological complexities, few lithium-ion batteries are recycled. - Health hazards pertaining to lithium-ion batteries include exposure to cobalt and manganese. - Batteries designed to combat climate change must be accountable for the health risks pertaining to their use.
Komendantova, N., Patt, A., Barras, L., and Battaglini, 'A. Perception of risks in renewable energy projects: The case of concentrated solar power in North Africa', *Energy Policy, Volume 40, 2012, Pages 103-109, ISSN 0301-4215,* *https://doi.org/10.1016/j.enpol.2009.12.008.* (https://www.sciencedirect.com/science/article/pii/S0301421509009458)	Regulatory risks - A lack of a stable framework - Constant changes in regulation which are difficult to navigate and therefore private markets avoid adoption - Uncertainty regarding future regulation Political risks - Political instability - Lack of support, commitment and cooperation Force majeure - Terrorism and sabotage - Security risks Additionally, the costs of projects and implementation are high and risky.
Killer, M., Farrokhseresht, M., and Paterakis, NG. Implementation of large-scale Li-ion battery energy storage systems within the EMEA region, *Applied Energy, Volume 260, 2020, 114166,* ISSN 0306-2619, *https://doi.org/10.1016/j.apenergy.2019.114166.* (https://www.sciencedirect.com/science/article/pii/S0306261919318537)	Microgrid complexity - Regulatory and legal framework is not yet rigidly in place

ANNEX 7: Deep dives

DEEP DIVE 1: MOBILE APPLICATIONS (MOBILE APPS)

This technology is wide ranging in focus covering multiple sectors from finance/ banking to healthcare, agriculture to leisure. It involves the development and use of ICT products on phones.

Mobile apps are important in that they can help address South Africa's triple scourge of unemployment, poverty and inequality. In terms of unemployment, the informal sector absorbs those excluded from formal employment and creates employment for the unemployed. However, businesses in this sector are financially excluded and most are unbanked. CreditRegister (Ortlepp, 2019) and Record Block (Saba, 2021) are blockchain-based apps (both at research stage) that have the potential to help businesses in the informal sector access credit, resulting in financial inclusion and sustainability.

In addressing poverty, the PC4IR reports that mobile apps have the potential to create access to food by simplifying supply chains and allowing consumers to be directly connected to the farmer. This has the potential to make food cheaper and eradicate poverty.

This study has identified the following projects in the mobile apps/ software space in South Africa:

TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Non-thermal plasma technology	- Mobile applications - Sensor technologies	- Nelson Mandela University - LEAP-Agri - Soil Research Institute (Ghana) - National Agricultural Research Organisation (Uganda) - Eindhoven University of technology (Netherlands) - Associação Fraunhofer Portugal Research (Portugal)	On-site fertiliser production mini-plants to provide cost-affordable fertiliser. Combined with the development of sensors and ICT technology to enhance the quality of soil and food production. Research is based on nitrogen fixation with non-thermal plasma technology. The project is being tested at plants built in Uganda, South Africa and Ghana.
Investment decision-making tool	- Software application	- DNA Economics	A tool for companies and financial institutions to effectively consider climate-related financial risks and opportunities (CFROs) when making investment decisions. Funded by the South Africa-UK Partnering for Accelerated Climate Transitions Programme.
Web-based legal services	- Mobile money/ banking	- Keakopa - Consumatech	Web-based solution that allows users to create simple contracts when lending money to friends and family. Also supports debt recovery services. Developed by Keakopa, supported by Consumatech.
NutriLeap	- Diagnostic technologies - Mobile applications - Artificial Intelligence	- HealthLeap	Founded in 2021, HealthLeap is a South African health technology firm focusing on the US market. Awarded US$1.1 million pre-seed funding by venture capitalist Fifty Years to develop a clinical aid for dieticians with a focus on US market. Announced 6 January 2022.
Municipal water and sanitation leaks management platform	- Mobile applications - Software applications	- City Park Trading 127 CC - Technology Innovation Agency	An app system to be used by municipalities to monitor and manage water and sanitation faults to reduce water and improve responses to faults. Currently being developed and tested.

TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Endotrachea tube-retaining device	- Cloud computing - Software applications	- Jirehsa Medical (Pty) Ltd - South African Medical Research Council	Patents on the device have been granted in European designated countries (UK, France, Germany, Spain, Ireland and Italy) as well as South Africa, Australia and the USA. The technology developers are seeking partners for the commercialisation and international marketing of the product as an intubation device to be used in the anesthesiology and emergency medical services sectors.
GIFT Genital InFlammation Text	- Mobile applications	- University of Cape Town - South African Medical Research Council	A low-cost, point-of-care test to identify genital inflammation associated with sexually transmitted infections in symptomatic and asymptomatic individuals. Has undergone clinical trials. National phase patent applications are pending. The technology developers are seeking commercialisation partners for the technology.
Optronic Scene Simulator (OSSIM)	- Software application	- Council for Scientific and Industrial Research	OSSIM is an engineering development tool. The simulator is written in C++ and runs on Windows and Linux systems. Current applications are mainly in the defence domain, but OSSIM can also be applied in the civilian world.
Spacedecode	- Software application	- Lepsta (Pty) Ltd - Technology Innovation Agency - Geekulcha - WeThink Code	Self-managed software development platform which enables collaboration and real-time sharing of source code between developers. Enabling coding, correction, and agile deployment of quality-assured software amongst software developers.
MALII Smart mobility platform	- E-commerce - Mobile banking/ mobile money	- MALII Fintech - SAB Foundation - Rand Merchant Investments	MALII is an app that enables taxi commuters to make payments without using cash, currently being piloted in Gauteng province with plans to scale nationwide. Addresses the cash payment system, financial exclusion, and inefficiencies in the minibus taxi industry.
Aeroview platform	- Artificial intelligence - Drones - Mobile technologies	- Aerobotics - Naspers Foundry	Planning, monitoring and control centre for farmers. Using aeronautics and machine learning technologies to process aerial imagery and identify problems. Founded in 2014, Aerobotics is currently operating in 18 countries.
Khula Inputs app, Funder Dashboard and Fresh Product Marketplace	- E-commerce - Mobile applications	- Khula App (Pty) Ltd - AECI Ltd - E-Squared Investments	Khula provides small-scale and commercial farmers with a software, product marketplace, and institutional funding platform. Launched in 2019, the company has signed up more than 3,000 farmers, and over 100 suppliers now work with the company.
SwiftVEE mobile app	- E-commerce - Mobile applications	- SwiftVEE - Google Launchpad - Subtropico Limited	Online auction platform enabling the buying and selling of livestock products where farmers can register and make bids online or watch live online auction video streams. Developed by start-up SwiftVEE which was founded in 2017. Currently the largest independent livestock trading platform.

TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Point of sale card machines	- E-commerce - Mobile banking/ money	- Yoco Technologies - Dragoneer Investment Group	Point of sale applications, payment gateway and card machines providing access to offline and online payments for small and independent businesses. Yoco was founded in 2013 and has raised $102 million in financing since inception.
Digital escrow platform	-Mobile banking/ mobile money	- TruZo - UK-South Africa Tech Hub	TruZo, a digital escrow platform, acts as a trusted third-party payment provider to both buyers and sellers of online and real-world transactions.
Lula mobility platform	- E-commerce - Mobile application	- Lula Loop (Pty) Ltd	Mobility platform that provides a transport service for businesses and private clients, connecting corporate commuters to safe, affordable, and sustainable shuttles.

ACTORS

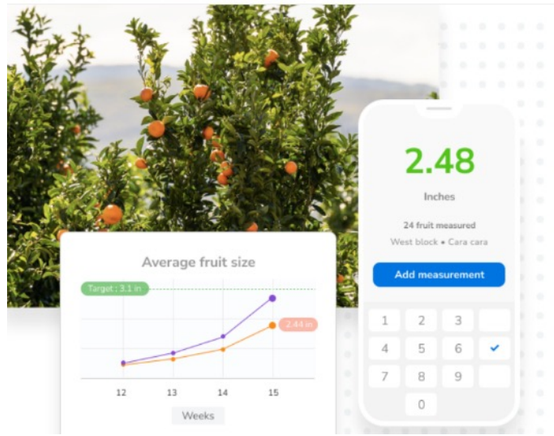
The main actors in this space are mostly in the private sector and include Abalobi ICT4Fisheries, Aerobotics and Yoco Technologies as noted in the following table:

PUBLIC SECTOR ACTORS	PRIVATE SECTOR ACTORS	OTHERS
University of Cape Town University of Pretoria University of the Witwatersrand	Abalobi ICT4Fisheries Aerobotics City Park Trading 127 CC DNA Economics HealthLeap Truzo (Pty) Ltd Yoco Technologies	UK PACT uYilo eMobility Programme Naspers Foundry (lead) Cathay Afrikaners Innovation, FMO: Entrepreneurial Development Bank Platform Investment Partners Fifty Years (VC) AECI E-Squared Investments Dragoneer Investment Group Velocity Capital Fintech Ventures Partech (and seven others)

There is little visibility of universities, public research institutes and councils in the mobile application space. Nevertheless, there is some work documented in the literature and it appears that there are collaborations between local and international universities in mobile application technology research. In the health sector for example, health mobile apps are being developed to deal with various issues facing the sector. One example is mHealth used as a screening tool for neurocognitive impairment (NCI) in HIV patients, of which South Africa has seven million. NCI is one of the most common complications of HIV infection and if not screened for, has serious medical and functional consequences (Robbins, Gouse, Brown, Ehlers, Scott, Leu, Remien, Mellins and Joska, 2018). Another app was developed for Tuberculosis (TB) patients to determine the right dosage for medication as individuals respond differently to TB medication leading to over and under dosage and causing hearing loss (Hollander, Joubert and Schellack, 2020). The research is a result of partnership between universities. The former app was a collaboration between South African and International universities including the University of Cape Town and the University of Columbia. The latter app was a collaboration between the University of Pretoria and the University of the Witwatersrand.

In the private sector, Abalobi ICT4Fisheries developed a mobile app currently used by small-scale fishers along the South African coast for fishing data such as seafood traceability and supply chain, to support ecological, economic and social sustainability. In the agricultural sector, through the use of drones and AI to process aerial imagery for the identification of problems invisible to the naked eye, Aerobotics developed a mobile app for digital monitoring of such problems (e.g. pests, disease pressure increases). The app also allows the farmer to check inventory of trees and fruit size count, with real time in-field reporting. This in turn assists the farmer to make swift decisions, resulting in sustainable farming.

Figure: Fruit size count report from Aerobotics developed app



Source: www.aerobotics.com

POLICY SUPPORT

We could not find any national policy in South Africa, drafted for the purpose of guiding the mobile applications industry. Although this is the case, mobile apps are subject to South Africa legisation such as the Cybersecurity Act and POPI Act. Mobile apps require personal information such as name and e-mail address and these acts govern personal data acquisition and dissemination and address the lawful and unlawful conduct of managing such information, to protect the consumer. Furthermore, mobile app developers have internal privacy policies, which the consumer must agree to before using the app. These address the type of information to be collected and for what purposes. Security issues are also addressed in some internal policies.

On a global level, the GSMA (global organisation unifying the mobile ecosystem) has a footprint in sub-Saharan Africa. Among their key activities is the advancement of policy and regulations in the mobile sector. In that regard, they have developed a mobile handbook policy (www.gsma.com/publicpolicy/wp-content/uploads/2022/03/Mobile-Policy-Handbook-2022.pdf). In this handbook, topics such as consumer protection, spectrum sharing and the business environment are discussed.

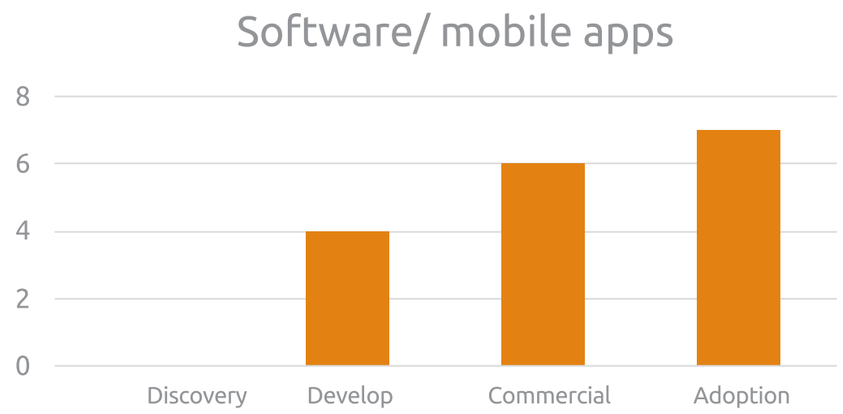
FUNDING

As discussed, key funders such as Cathay AfricInvest Innovation, Fifty Years (VC), E-Squared Investments, Dragoneer Investment Group and Velocity Capital Fintech Ventures are visible in this space. Notable investments in the last couple of years include US$83 million raised by Yoco Technologies in July 2021 as well as US$27 million raised by Aerobotics, a South African start-up providing tools for precision agriculture.

Moreover, pockets of funding in both the private and public sector are visible. The Cape Town based 4DI Capital provides very early stage funding to mobile proprietary owned software entrepreneurs. Most beneficiaries are apps that use 4IR technologies as a base such as BFree (machine learning), Tagmarshal (Internet of Things) and Comparisure (AI). From the government side, it appears there was a collaboration between TIA and MLab called the New App fund, which was to fund mobile app and wearable device start-ups to develop their concepts (https://mlab.co.za/new-app-fund-launched/)

STAGE OF DEVELOPMENT

Details in Annex 5 highlight the following breakdown of mobile/ software apps at different stages of development.



It can be seen that there are no projects identified at discovery stage while most projects are identified at adoption/ diffusion stage. As stated elsewhere in the report, this is particularly pertinent for the waning emerging technologies, such as mobile technologies.

The key issues faced by mobile and software app developers across these stages of development include increasing recognition of risks, harms and security issues. Risks associated with mobile application technology are generally related to personal data and data security such as sensitive data leakage (where a poorly designed app can leak sensitive data e.g. your location to third parties) and impersonation and phishing (where sensitive data such as passwords can be given to impersonators of banks or other institutions). Consumers and users of mobile apps are somewhat protected by the Cybersecurity Act as well as the Protection of Personal Information Act, which govern the lawful and unlawful handling of personal data.

DEEP DIVE 2: NEXT GENERATION (NEXT GEN) MEDICINE

The next gen medicine sector mainly concentrates on drugs, medical treatments and their delivery. However, we have included medical diagnostics and veterinary medicine in our definition for this study, in line with the CSIR's definition of 'next gen health'. The CSIR's focus areas are:

- Synthetic biology and precision medicine including industrial synthetic biology and nanobiomachines, bioengineering and integrated genomics, microarray-based technologies and proteomics
- Veterinary vaccines and diagnostics including lab-on-chip, point-of-care solutions for veterinary, aquaculture and diagnosis of zoonotic diseases
- Human molecular diagnostics and omics
- Diagnostic laboratory testing

(see: https://www.csir.co.za/nextgen-health)

The significant level of patenting in this area (see Section 3.2.1) as well as the number of projects/ technologies identified during the literature review for this study highlights the depth of focus in South Africa on this area of technology. In fact, Gelaw et al. (2016) observe that the availability of a large number of medicines and the constant influx of new information make it practically impossible for any health care professional to be up-to-date in all aspects of a new medicine. That said, De Haan et al. (2020) opine that the emergence of 4.0 technologies is leading to a pathway where next-generation medicine will be of exponential value for the overall healthcare ecosystem. This is because next gen medicine will be able to integrate healthcare into digital ecosystems linked by innovative interfaces, advanced analytics, customer-centric models and digital epidemiology surrounding a new concept of health and disease management, as enabled by 4IR.

This study has identified the following projects involving next generation technologies in South Africa:

TECHNOLOGY	KEY SOUTH AFRICAN ACTOR	DESCRIPTION
Multivalent inactivated vaccine against heartwater	- Agriculture Research Council	Production of a high-quality, heat-stable, affordable multivalent inactivated vaccine against heartwater (HW) to support sustainable agriculture for smallholder farmers.
Prosthetics and medical devices	- Central University of Technology - Centre for Rapid Prototyping and Manufacturing - Department of Science and Innovation - Manufacturing, Engineering and Related Services Sector Education and Training Authority	Medical prosthetics.
3-Tiered Smart Screening Cascade for Malaria	- Centre for Scientific and Industrial Research (CSIR) - National Health Laboratory Service - South African Medical Research Council - University of Pretoria	An in vitro platform to screen transmission-blocking antimalaria compounds against gametocytes and gametes.

TECHNOLOGY	KEY SOUTH AFRICAN ACTOR	DESCRIPTION
Antimonia	- South African Medical Research Council	Antimonia is a point-of-care diagnostic system/ solution for differential diagnosis of bacterial and viral pneumonia in under 40 minutes.
Aspalathin therapeutic preparations	- South African Medical Research Council	Aspalathin-rich green rooibos extract (GRT extract) and synthetic aspalathin as novel therapeutic preparations for the treatment and management of metabolic disease. Phase one trials completed.
Bi-SP microbicide complex	- National Health Laboratory Service - South African Medical Research Council	Bi-SP complex is a low-cost, stable, rapidly solubilised active pharmaceutical ingredient that can be formulated into a microbicide with low toxicity towards mammalian cells and vaginal Lactobacillus clinical strains and broad microbicidal activity against most sexually transmitted pathogens, including HIV.
Cardioflow	- Technology Innovation Agency	Portable, hand-held, point-of-care (PoC) screening device able to identify patients at risk of cardiovascular disease.
Flucytosine	- Msizi Pharmaceutical Holdings - Nelson Mandela University - Technology Innovation Agency	A recommended treatment for cryptococcal meningitis by the World Health Organization.
Marker serum proteins for early-stage diabetes	- South African Medical Research Council	The technology includes two marker serum proteins for the early detection of people at risk for diabetes. Patent applications to be filed once the prototype device has been developed and validated.
Medsol breast AI	- Medsol AI Solutions - SAB Foundation	Online patient-based platform that receives images for ultrasound units in practice. Software designed for breast cancer identification and segmentation for breast ultrasound in the diagnostic imaging sector using deep machine learning and artificial intelligence.
mRNA Covid vaccine	- Afrigen Biologics and Vaccines - Avacare Healthcare Group - Industrial Development Corporation	mRNA vaccine developed by Cape Town-based biotechnology company Afrigen Biologics.
NutriLeap	- HealthLeap	A clinical aid for dieticians.
PrCr Urine dipstick text	- South African Medical Research Council	A Protein/ Creatinine rapid test for determining proteinuria status as onset indicator of Preeclampsia/ Eclampsia. Currently undergoing clinical testing.
Prosopis Glandulosa	- South African Medical Research Council	A cost-effective, novel therapeutic agent for treating contused muscle tissue and recovering skeletal muscle strength. Animal studies have been completed.
Roboleg	- House4Hack - Robohand	3D printed prosthetic leg to mitigate the high costs of current prosthetics.

TECHNOLOGY	KEY SOUTH AFRICAN ACTOR	DESCRIPTION
TB SERS Biosensor	- University of Cape Town - South African Medical Research Council	TB SERS Biosensor is a novel, hand-held, battery operated POC TB diagnostic device.
Aparito's Atom5™	- Aparito - South African Medical Research Council - University of Cape Town	Wearable device used for remote long-term epileptic patient monitoring outside of the hospital.
Ellavi Uterine Balloon Tamponade (UBT)	- Sinapi Biomedical -- South African Medical Research Council - PATH	The Ellavi UBT is a preassembled medical device used to address post-partum bleeding.
Endotrachea tube-retaining device	- Jirehsa Medical (Pty) Ltd - South African Medical Research Council	An intubation device to be used in the anesthesiology and emergency medical services sectors.
GIFT Genital InFlammation identifier	- University of Cape Town - South African Medical Research Council	A low-cost, point-of-care test to identify genital inflammation associated with sexually transmitted infections in symptomatic and asymptomatic individuals.
Optishunt	- Liqid Medical - SAB Foundation - Technology Innovation Agency	Novel ocular implant designed to improve the treatment of glaucoma.
TB-PROTEC	- Antrum Biotech (Pty) Ltd - South African Medical Research Council - University of Cape Town	Field-friendly rapid TB diagnostic tools.
Electromyogram device	- South African Medical Research Council	A non-invasive, easy to use device for measuring deep muscle electromyogram using surface electrodes.
TeleSensi™ Cardiac	- TeleSensi	An AI powered murmur screening service. Available as a stand-alone product or integrated with TeleSensi™, a cloud-based telehealth service with integrated stethoscope streaming, user management and auscultation guide
Umbiflow™	- Centre for Scientific and Industrial Research (CSIR) - South African Medical Research Council - University of Cape Town - World Health Organization - Bill and Melinda Gates Foundation	A novel portable continuous-wave Doppler ultrasound to be used in estimating the rate of flow of blood in the umbilical cord, allowing health care practitioners to ensure sufficient supply of oxygen and nutrition to a growing foetus.
Altis Osteogenic Bone Matrix	- Altis Biologics	Injectable bone morphogenetic proteins capable of inducing new bone formation commencing shortly after implantation into human recipients.

IMPORTANCE OF THIS TECHNOLOGY FOR SOUTH AFRICA'S DEVELOPMENT

The PC4IR states: "Even as digital advances begin to take life sciences to the brink of radical reinvention, healthcare continues to face the triple endemic challenges of lack of access, high costs and poor outcomes. Informed, tech savvy consumers are demanding better health services. South Africa, a country where 80 percent of the populace relies on failing public health services, digital technologies can make significant difference." (PC4IR, 2020: 63). The relationship between the health of the population and economic and social development is acknowledged in South Africa's National Development Plan. Thus there is policy pressure as well as commercial pressure to use new technologies to combat existing and new illness and disease. Despite the fact that investment in new medical technology has brought about significant advances in patient care, new medical advances are often implicated in increasing health care costs. The matter is not a simple one, as the commitment to controlling health costs may conflict with innovation and development in medical technology.

Emergent technology in health care and next generation health should be a key enabler in the response to health, economic, and social disruptions caused by infectious diseases such as COVID-19. This should be possible through the ongoing development and deployment of diagnostics, community- and self-testing through automated tools and artificial intelligence-powered methods such as emergent technologies in the health care discussed above. They can also be essential for early warning and disease surveillance. In addition to case identification by online symptom reporting, data aggregation systems can provide epidemiological insight and play an important role in epidemic surveillance. Furthermore, these emergent technologies powered by digitalisation can also contribute to well-established low-technology solutions, such as educating patients about their health care, text message reminders for check-ups and taking medication, and community-based peer support groups (UN Commission on Science and Technology, 2021).

ACTORS IN THE NEXT GEN MEDICAL FIELD

The main actors identified by this study as working in this space include the following stakeholders. This is not an exhaustive list but highlights the dominance of both public and private sector actors. We found very few mentions of other actors (e.g. the third sector or community groups) involved, however, we are aware that these stakeholders are core to healthcare services in South Africa and therefore are likely to play a role in technology roll out, even if not documented in the references reviewed or interviews undertaken for this study.

PUBLIC SECTOR ACTORS	PRIVATE SECTOR ACTORS	OTHERS
Biosafety South Africa DSI TIA CSIR IDC NRF South African Medical Research Council University of Cape Town Stellenbosch University University of Pretoria Central University of Technology Gauteng Growth and Development Agency Department of Health	Avacare Healthcare Group HealthLeap House4Hack Khepri Innovations Life Assay Diagnostics Liqid Medical Lodox Systems Msizi Pharmaceutical Holdings Sinapi Biomedical TokaBio (Pty) Ltd Microsoft South Africa	Vantage Health Technologies

Source: *authors based on review of literature and interviews*

POLICY SUPPORT

The following policies are used to promote, regulate and incentivise work in South Africa and at regional level in the area of next generation health:

PROMOTE	REGULATE	INCENTIVISE
PC4IR focuses on telemedicine, predictive analytics and precision medicine White Paper on STI of 2019 Department of Health Strategic Plan	IPAP (Industrial Policy Action Plan) POPIA IP policy	National Digital Health Strateg

Source: *authors based on review of literature and interviews*

FUNDING

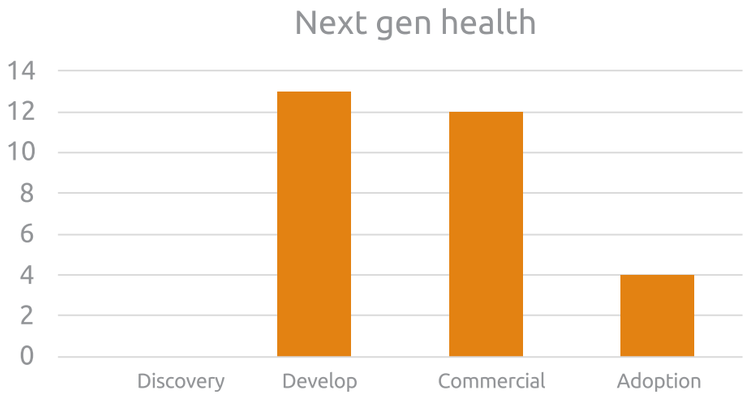
As noted under actors, the funding agencies are the TIA, CSIR, South African Medical Research Council, DSI, CSIR, IDC and NRF. The TIA, CSIR and SAMRC are particularly visible in this space. Notable investments in the last couple of years include the TIA which has committed R45 million to the Altis Osteogenic Bone Matrix to assist Altis Biologics to build a pilot plant, train an operations team, conduct clinical trials, obtain regulatory approval and commence small-scale production. There has also been a commitment of R12 million from TIA and R30 million from the IDC for the development of Lodox's next generation X-ray machines in 2020/2021. Optishunt has a funding commitment of R9.4m over three years to support device refinement, clinical trials, and regulatory certification. Stellenbosch University has made a R300 million contribution to the construction of the Biomedical Research Institute at the University, which will eventually cost R1 billion.

Annex 4 also identifies Atlis Biologics and HealthLeap as key funders in this space.

The funding of next gen health continues to improve. Both government and private entities are playing a key role in providing funding mechanisms. For example, the NRF has a funding programme for next generation researchers in medicine. The National Digital Health Strategy for South Africa (2021 – 2024) aims at developing sustainable and appropriate investment and funding for the sector through the establishment of a national grant for digital health implementation in conjunction with National Treasury. This aims to align and coordinate investments, targeting a proportionate allocation of three to five percent of total government expenditure on health.

STAGES OF DEVELOPMENT

Details in Annex 5 highlight the following breakdown of next generation health technologies at different stages of development.



Source: *authors (based on Annex 5)*

At the developmental stage we find several projects including 3D Bioprinting, development of Prosthetics, and the 3 tiered Smart screening cascade for Malaria. In addition, we have the Antimonia diagnostic tool, Aspalathin Therapeutic interventions, BI-SP Microbicide Complex, Cardillo, Flucytosine, TB SERS Biosensor and others.

At the commercialisation stage we find technologies such as the Aparito's Atom5™, Ellavi Uterine Balloon Tamponade (UBT), Endotrachea tube-retaining device, GIFT genital inflammation detector, Electromyogram device, OptiShunt, TB-PROTEC and Umbiflow.

Few technologies identified are at the diffusion stage. These include Altis Osteogenic Bone Matrix and TeleSensi. No technology projects were identified at the discovery stage.

Bottlenecks to the development of next gen health and medicines at the development stage have been identified as including establishing innovation value and effort needed to bring the product to the market. It also includes sourcing funding to drive the development of the product, and the application of industry standards to the development of the product (Loftus, 2015). For example, before initiating clinical development studies, regulatory authority normally has to be sought from bodies such as the South African Medical Research Council. At the commercialisation stage, bottlenecks include increasing costs and the pressure of pricing (Yildrim et al., 2016). Getting regulatory approval from relevant bodies can also be a bottleneck as can obtaining private partner collaborations to market the next gen medicine and establishing partnerships between the developer and private sector. Yildrim et al. (2016) observe that partnerships can be classified based on the types of participants or on the scope and duration of the project, which may fall in the competitive or pre-competitive space. Each comes with a specific balance of responsibilities. The issue of IP and the processes involved, especially in South Africa, can be a bottleneck mainly due to bureaucratic red tape. Strategic alliances between a developer and a research institution can mitigate this. At the diffusion stage, the establishment of value chains and getting the product to the market can be a challenge. In the healthcare context, the process of diffusion is complex. There are a range of stakeholders including the adopting organisation, clinicians, and the payers who all have different characteristics, preferences, and motivations. Getting all the stakeholders to agree on the diffusion process can be an obstacle. In addition, issues like clinical evidence, jurisdictional requirements, adoption and regulatory requirements can all be obstacles to the diffusion process of next gen health and medicines.

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DEEP DIVE 3: ARTIFICIAL INTELLIGENCE

In this deep dive artificial intelligence (AI), refers to the use of computers to sense, think and learn to conduct tasks.

Importance of artificial intelligence for South Africa's development

Optimistically, the development and adoption of artificial intelligence offers promise with Accenture (n.d.) stating that it may drive economic growth and has the potential to double a country's GDP by 2035. One of the PC4IR's (2021) core recommendations is the establishment of an artificial intelligence (AI) Institute which is aligned with the Commission's broader objective for a 'globally competitive, inclusive and shared economy with the technological capability and production capacity that is driven by people harnessing the Fourth Industrial Revolution to propel the country forward towards its social and economic goals.'

The University of Pretoria (n.d.) conducted a detailed study of how artificial intelligence can foster growth, development, and democratisation in Africa, stating that it presents widespread opportunities for the continent. However, it requires forward-thinking policymakers and private and public actors to fully harness the potential of AI. The illustration from the report reproduced below depicts how AI can positively impact several spheres that are crucial to economic and social development and growth.

HEALTH

At offers vast opportunities to transform how we understand disease and improve health.

TRANSPORTATION

Al can provide safe and efficient transportation; expand the capacity of existing road infrastructure and improve traffic flow. It can also reduce carbon emissions and facilitate greater inclusiveness.

EDUCATION

Al can develop predictive models for engagement and comprehension. It can be used to develop new approaches to education that may revolutionise how people learn.

PUBLIC SERVICES

Al can improve how governments interact with their citizens and deliver services. It can create efficiencies, reduce burdens, and eliminate redundancies.

FOOD PRODUCTION

Al offers significant opportunities to increase food production by improving agricultural yield and reducing waste.

DISABILITIES

Al can help address some of the problems faced by the more than 80 million people in Africa.

During our review we have identified the following projects in the AI space in South Africa.

TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Artificial Intelligence	- Artificial intelligence	- Centre for Artificial Intelligence Research (CAIR) - Sol Plaatjie University - Stellenbosch University - University of Cape Town - University of KwaZulu-Natal - University of Limpopo - University of Pretoria - North-West University	Basic and applied research in artificial intelligence including machine learning, deep learning, knowledge representation and reasoning and speech technology. The Centre for Artificial Intelligence Research (CAIR) was founded in 2011 and has established nodes and research networks with universities.
Medsol breast AI	- Artificial intelligence - E-commerce	- Medsol AI Solutions - SAB Foundation	Online patient-based platform that receives images for ultrasound units in practice. Software designed for breast cancer identification and segmentation for breast ultrasound in the diagnostic imaging sector using Deep Machine Learning and Artificial Intelligence. Received funding in 2021 form SAB foundation.
NutriLeap	- Diagnostic technologies - Mobile applications - Artificial intelligence	- Health Leap	Founded in 2021, HealthLeap is a South African health tech firm focusing on the US Market. Awarded US$1.1 million pre-seed funding by venture capitalist Fifty Years to develop a clinical aid for dieticians with a focus on US market. Announced 6 January 2022.
HYDRA Holistic Agriculture and HYDRA Conversation	- Artificial intelligence - Big data - Cloud computing	- The Awareness Company (Pty) Ltd - Microsoft South Africa	Founded in 2018, the company uses data-driven storytelling combining AI, IoT and data analytics to create solutions for agriculture and conservation, safety and security, and smart buildings and cities. Microsoft South Africa has funded the development of agricultural applications of its HYDRA technology.
Pneumonia Diagnostic Tool Suite	- Artificial intelligence - Diagnostic technologies	- Mr Storm Rhoda - Regeneron - SAB Foundation	Machine learning model that can identify and distinguish between lungs that are infected and those that are not infected by pneumonia in an efficient manner.
Vantage health equity dashboard	- Artificial intelligence - Cloud computing	- Vantage Health Technologies - Microsoft	Vantage Health Technologies, a South Africa-based company that provides cloud-based and AI solutions for health equity challenges. Announced US launch in 2021. Key partners include Microsoft

TECHNOLOGY	TECHNOLOGY CLUSTER	KEY ACTORS	DESCRIPTION
Wide Area Surveillance System	- Artificial intelligence - Optical imaging technologies	- Council for Scientific and Industrial Research	Used in the detection of small craft in the maritime environment, specifically in support of anti-piracy operations. Omni-directional viewing capability, with the ability to perform real-time stitching, background modelling and target tracking.
Aeroview platform	- Artificial intelligence - Drones - Mobile technologies	- Aerobotics - Naspers Foundry	Planning, monitoring and control centre for farmers. Using aeronautics and machine learning technologies to process aerial imagery and identify problems. Founded in 2014, Aerobotics is currently operating in 18 countries.
TeleSensi™ Cardiac	- Artificial intelligence - Diagnostic technologies	- TeleSensi	An AI powered murmur screening service. Available as a stand-alone product or integrated with TeleSensi™, a cloud-based telehealth service with integrated stethoscope streaming, user management and auscultation guide
AI models to predict consumer behaviour	- Artificial intelligence - Big data	- Xineoh	Application Programming Interface (API) platform enabling the prediction of customer behaviour using artificial intelligence. South African start-up headquartered in the US with operational headquarters in South Africa.
Aeroview platform	- Artificial intelligence - Drones - Mobile technologies	- Aerobotics - Naspers Foundry	Planning, monitoring and control centre for farmers. Using aeronautics and machine learning technologies to process aerial imagery and identify problems. Founded in 2014, Aerobotics is currently operating in 18 countries.
TeleSensi™ Cardiac	- Artificial intelligence - Diagnostic technologies	- TeleSensi	An AI powered murmur screening service. Available as a stand-alone product or integrated with TeleSensi™, a cloud-based telehealth service with integrated stethoscope streaming, user management and auscultation guide
AI models to predict consumer behaviour	- Artificial intelligence - Big data	- Xineoh	Application Programming Interface (API) platform enabling the prediction of customer behaviour using artificial intelligence. South African start-up headquartered in the US with operational headquarters in South Africa.
Virtual advisors	- Artificial intelligence - Automation software	- CLEVVA (Pty) Ltd - Blue Prism Ltd	Artificial intelligence-powered virtual advisors, used in to train and guide sales representatives. CLEVVA has partnered with UK-based robotic process automation (RPA) firm Blue Prism to automate front-office sales and support journeys across staff-assisted and self-service.
Autonomous electric vehicle (EV) assembly line	- Artificial intelligence - Industrial robots	- Jendamark	Autonomous electric vehicle (EV) assembly lines commissioned by a Silicon Valley startup, in California. Jendamark is a South African firm that offers turnkey production solutions. The project was completed in 2020.

ACTORS

There is strong visibility of South African funding agencies, universities, and private sector companies.

The main actors in this space, as depicted in the table below, span across the public and private sector and are made up of regional and international partnerships. Public funding institutions and actors within the artificial intelligence space in South Africa include the Technology Innovation Agency (TIA), the Department of Science and Innovation (DSI), the National Research Foundation (NRF) and several public universities. DSI works in collaboration with a several organisations on AI-focused, and other, emerging technology projects.

Centre for Artificial Intelligence Research (CAIR) is funded by the Department of Science and Innovation and consists of several research groups that have an AI focus in universities across South Africa. Research groups include the ethics of AI, AI for development and innovation, and statistics at the University of Pretoria, a swarm intelligence lab at Sol Plaatjie University, speech technologies at the University of Limpopo, adaptive and cognitive systems lab and knowledge representation and reasoning at the University of Cape Town, computational thinking for AI at Stellenbosch University, AI and cybersecurity at the University of Western Cape, deep learning at North-West University, and CAIR at the University of KwaZulu-Natal. The University of Pretoria stands out as one of the leading public universities in South Africa developing several start-ups and patents in the realms of artificial intelligence and other emerging technologies. It receives significant funding from TIA and DSI.

Within the private sector, several private firms operate in the artificial intelligence space, with a few collaborating with other public or private actors for the advancement of artificial intelligence. These companies include, Aerobotics, Microsoft South Africa and The Awareness Company. Additional actors are listed below.

ACTORS IN ARTIFICIAL INTELLIGENCE IN SOUTH AFRICA

PUBLIC SECTOR ACTORS	PRIVATE SECTOR ACTORS	OTHERS (I.E PARTNERSHIPS)
Department of Science and Innovation	Aerobotics	Smart Africa Alliance
Technology Innovation Agency	CLEVVA	CLEVVA and Blue Prism Limited (UK)
Centre of Artificial Intelligence Research	Jendamark	Vantage Health Technologies and Microsoft South Africa
Academy of Science of South Africa (ASSAF)	Medsol AI Solutions	
National Research Foundation	Microsoft South Africa	
North-West University	TeleSensi	
Sol Plaatjie University	The Awareness Company	
Stellenbosch University	Vantage Health Technologies	
University of Cape Town	Xineoh	
University of Western Cape		
University of Johannesburg		
University of KwaZulu-Natal		
University of Limpopo		
University of Pretoria		

Extracted from Annex 2: *Actors in the emerging technology space in South Africa*

POLICY SUPPORT

There is an extremely high degree of policy support for AI, mentioned in the PC4IR report with a recommendation for its own Centre and APET. There is significant public institutional support at a national and continental level, and support exists even with little regulation in place.

Minister Khumbudzo Ntshavheni of the Department of Communications & Digital Technologies South Africa, has stated that AI encourages innovation while maintaining the importance of regulation (2021). The minister also stated the need for African institutions to collectively agree on a common and united stance on AI and develop an African AI framework.

The Centre for the Fourth Industrial Revolution (C4IR) South Africa, was designed in 2019 and is spearheaded by the Department of Science and Innovation. It is responsible for advancing the 4IR in the country, and specifically focusing on designing smart regulation for technologies like AI and blockchain. It works in collaboration with government regulators and smart technology industries. A primary objective of the C4IR is to design a policy framework and regulations to guide the use of AI in South Africa (C4IR, 2022).

At a continental level, there are two primary drivers of policy support in the field of AI, the African Union High Level Panel on Emerging Technologies (APET) and the Artificial Blueprint of Africa. APET, established by the African Union, who brought in experts on emerging technologies to play support and advisory roles, is a high-level attempt to leverage the opportunities and possibilities of emerging technologies.

The Artificial Intelligence Blueprint for Africa is a product of Smart Africa (continental organisation with the vision of fast-tracked socio-economic development on the continent) and has made several proposals: 1) for the African continent to have regional Centres of Excellence for AI focused on different thematic areas and encouraging collaboration; 2) an ethical framework and guidelines for the use and adoption of AI, further prioritising human development as the central focus in AI adoption; 3) repositioning emphasising data preservation for the economic development, utilising data as an economic tool; 4) to highlight the economic sectors that have the potential for further advancement and development; 5) a high-level roadmap that states may utilise as a guideline for the adoption of AI; and 6) policy and regulatory recommendations around AI (Ntshavheni, 2021). Malinga (2022), states that the Artificial Intelligence Framework for South Africa has been completed, led by DTCD Minister Khumbudzo Ntshavheni. The framework formed part of the AI Blueprint for Africa. Furthermore, the framework will lead the process of establishing an AI hub to serve at several higher education institutions but based at the University of Johannesburg.

The Technology Innovation Agency (TIA) has stated that it supports the state's national objectives and therefore supports the design of ICT-led innovations that have significant socio-economic impact. In the 2020/2021 Annual Report, TIA highlighted several funded projects that are AI-driven with the huge potential of AI to transform the agricultural sector as one of the reasons for the large portion of funding. It also recorded that R6.7 million of its annual budget was dedicated to a project on AI.

The following policies are used to promote, regulate and incentivise work in South Africa and at a regional level in the area of artificial intelligence, as derived from annex 3.

PROMOTE	REGULATE	INCENTIVISE
AI Framework for South Africa	Protection of Personal Information Act	12L: Tax Allowance Incentive
TIA Sector Funding	International Telecommunications Union (ITU) called for AI for Good	Section 11D: Research and Development Incentive (R&D)
Global Cleantech Innovation Programme	AI Blueprint for Africa	Section 12R: Special Economic Zone (SEZ)
Imvelisi's Enviropreneur Programme	AI Framework for South Africa	
Incubation programmes		
Innovation Skills Programme		
Youth Technology Innovation Programme		
Innovation for Inclusive Development		
Khoebo Innovation Promotion Programme (KIPP)		
Pre-Commercialisation Support Fund		

As previously highlighted, South Africa has several acts related to intellectual property and protections, this is crucial as the country has a growing list of patents that is being produced, with 108 artificial intelligence patents developed thus far. Patent protection acts include: the Patents Act 57 of 1978 and Copyright Act 98 of 1978 (and Copyright Amendment Act, 2018). The Minister for DTCD has called on the country to abide by the ITU AI for Good guidelines.

AI is data-driven and the larger the quantity of input data, the more sophisticated the AI system becomes. However, with more data in use, it becomes increasingly complex with legalities surrounding it. While businesses may have access to data, they may or may not be able to use it. The Protection of Personal Information Act (POPIA) is a crucial consideration when dealing with AI and the creation of AI systems and algorithms. Section 71(7) of POPIA makes specific reference to AI-driven processes and the governance of automated decision-making, attempting to protect citizens from automated systems used by banks and other institutions to determine loans and job applications (Mostert and Tembedza, 2020).

South Africa's 2019 update on the White Paper for Science, Technology and Innovation makes specific reference to artificial intelligence as a product of the fourth industrial revolution.

FUNDING

Significant research funding is put into artificial intelligence and there are a few examples of venture capital funds.

Private funding includes Ethos which runs an AI investment fund that looks to fund businesses that can significantly benefit from AI. The fund was launched in 2018 with a R750 million target and is currently funding projects to the value of R640 million. These include Tyme Bank, Cross Fin, Vertice MedTech Group and Channel VAS (Ethos, 2022). Algorithmic decision making is the primary focal point of Ethos-funded projects. There are also several other private funding organisations.

Aerobotics, a South African-based start up uses artificial intelligence, drones and mobile applications to provide tools for precision agriculture. Aerobotics has raised US$27 million, with the latest round of US$17 million announced in January 2021. Funders include Naspers Foundry (lead), Cathay AfricInvest Innovation, FMO: Entrepreneurial Development Bank and Platform Investment Partner.

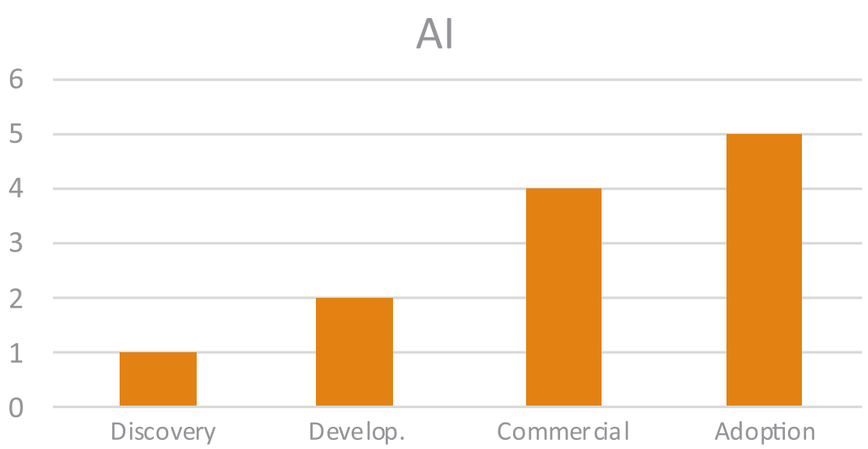
STAGE OF DEVELOPMENT

Most technologies identified are focused at commercialisation and adoption. Few are visible in the early stages despite significant research programmes in this area.

In an interview with a respondent from the University of Pretoria, it was stated that most technologies employed in their activities are in their embryonic phases when adoption takes place. Artificial intelligence is one of the most frequently applied technologies within the unit and he further echoed that the embryonic stage was important as at this stage, technologies are relatively agile and may be applied in different scenarios. In most cases, earlier development occurs by private organisations with substantial skills, knowledge, and resources to be producers of AI-led products and services. Figure 7 highlights the stages of development, and which is the most common stage of interaction. Furthermore, as depicted in Table 3 (Table 3. All patents registered for emerging technologies in South Africa, excluding patents filed internationally under the Patent Cooperation Treaty system), there are currently 108 artificial intelligence-related patents in South Africa.

Annex 5 illustrates the stages of development for artificial intelligence, detailing the sector and key actors involved. The total number of projects at each stage are provided in the figure below.

Few actors are involved in the discovery phase of artificial intelligence, however, most of the actors are public universities highlighting the research and experimentation that is being done at the institutions. Only two actors are part of the development stage. The commercialisation stage has a slightly larger pool of actors, from both the public and private sector. Lastly, the diffusion stage is the most expansive with several actors, highlighting that the adoption stage is the most common stage in the innovation lifecycle within the South African sphere.



Explaining the reason for the differences at the stages of development is not easy. Several interviewees highlighted a general lack of knowledge around AI and emphasised that it is problematic that in most cases, digital skills are only introduced at a tertiary level as opposed to other states where these are introduced in early school days. However, it was also noted that the South African government is making considerable efforts in this regard by introducing coding and robotics at primary school level as of 2023. Furthermore, there are small pools of funding that go to preferred institutions and a general lack of financial resources to fund and foster development, research and adoption around AI. Machine Learning Africa (2021) cites a lack of support and low levels of skills as hindering the adoption of AI. Similarly, Mzekandaba (2021) states that there are high costs affiliated with the adoption if AI, which South Africa's public sector cannot afford and echoes concerns regarding the skills shortage in the country.

Makina (2022) states that in South Africa, the positive ramifications of AI are already coming to fruition and evident in the agricultural and financial sectors that are positively transforming as a result. On the other end of the spectrum, there is notable concern about the use of data and privacy in the use of AI, as well as automated systems which may make discriminatory decisions based on gender, race, religion, or nationality. While regulation is taking place, regulatory frameworks are still lacking in the country, and it will take time for them to be applied across industries.

Travaly and Muvanyi (2020) consider the positive and negative aspects in the adoption of AI in Africa. Negatively, the lack of infrastructure, investors, skills and agile regulatory frameworks pose hefty barriers to adoption and implementation. However, the authors acknowledge the transformative opportunity that AI presents for Africa as it is able to amplify the continent's development and transform healthcare and agricultural sectors

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DEEP DIVE 4: E-COMMERCE

E-commerce transactions in South Africa encompass a variety of goods and services for the retail, business-to-business (B2B) and consumer-to-consumer (C2C) markets (Goga, 2021). For retail, fashion emerges as the largest category based on net sales of the top 100 online stores (ecommerceDB, 2022). Household appliances, health products and electronics are also leading categories (Schaefer and Bulbulia, 2021). Forms of e-commerce in South Africa include online stores, omnichannel retailers, third-party trading platforms, and social media platforms, accessed through two main channels, i.e., the internet and cellular telephony (Goga, 2021). According to Eden et al.(2021), smartphones are used most frequently for online shopping. This finding is consistent with South Africa's household access to internet profile – 64.1% of households access the internet using mobile devices while 89.4% of households use cellular phones exclusively for communication (Statistics South Africa, 2021).

In 2021, market research placed South Africa 41st in the global e-commerce market, with an estimated revenue of US$5 billion , a 19% year-on-year increase from 2020. Mirroring international trends, the COVID-19 pandemic boosted South Africa's e-commerce market (Schaefer and Bulbulia, 2021), with more businesses engaging in e-commerce in South Africa. Sales volumes are also increasing significantly, accompanied by increased business innovation in the market (First National Bank Limited, 2020; Goga, 2021). The compound annual growth rate is forecasted at 8% for the next four years (ecommerceDB, 2022).

Notwithstanding these developments, South Africa's e-commerce market has yet to fully transition from "nascent" pre-pandemic levels (Goga, 2021; Goga, Paelo and Nyamwena, 2019), suggesting further opportunities for innovation and new market entrants (Schaefer and Bulbulia, 2021). In 2021, trade (wholesale, retail and motor), catering and accommodation contributed approximately 12.9% of South Africa's GDP – the third-largest industry trailing only the personal services (15.6%) and finance, real estate and business services (23.5%) industries (Statistics South Africa, 2022). However, e-commerce likely constitutes a fraction of this trade; pre-COVID-19 pandemic, as little as 1-2% of total retail sales were classified as online (Goga, 2021). Little information on the current size and growth prospects in business-to-business (B2B) and consumer-to-consumer (C2C) trade is available in the public domain although Goga and Paleo (2019) note that B2B customers generally constitute about 90% of e-commerce transactions.

Our study found examples of emerging e-commerce technologies spanning several sectors in South Africa including human health and social work; financial and insurance activities; agriculture, forestry and fishing; and energy. Market share for online retail is concentrated in a handful of private actors with sizable balance sheets (ecommerceDB, 2022), which may account for emerging technology actors focusing on niche markets such as the domestic taxi industry, agriculture B2B and next generation health services. E-commerce technologies are also packaged or amalgamated with other emerging technologies to provide new offerings to South African consumers and businesses. Examples here include Yoco (Pty) Ltd which provides an online payment gateway for e-commerce in addition to offline point of sale products and work by the University of Johannesburg on a Smart Distribution Network Systems to control and manage energy consumption that interfaces with energy e-commerce. This study identified the following e-commerce projects involving next generation technologies in South Africa:

TECHNOLOGY	KEY SOUTH AFRICAN ACTOR	DESCRIPTION
AgriKool crowdfunding	- AgriKool	Providing smallholder farmers with finance and market linkage opportunities through its digital platform. Farmers are offered affordable, efficient and reliable options, and are linked to a network of informal vendors and supermarkets to sell their fresh produce.

[3] ecommerceDB excludes digitally distributed services, digital media downloads, and dedicated B2B and C2C platforms in its e-commerce market definition (ecommerceDB, 2022).

TECHNOLOGY	KEY SOUTH AFRICAN ACTOR	DESCRIPTION
Electric cargo vehicles	- Mellowcabs	Light electric cargo vehicles providing low cost, efficient and emission-free delivery services in cities. Offers bespoke client-specific offerings like active cooling and security features.
Genetic testing service	- Gknowmix - South African Medical Research Council	Integrated system for genetic testing service delivery involving healthcare practitioners, medical scientists, laboratories and the public. Gknowmix was founded in 2007 as a spin off company from the South African Medical Research Council.
Khula Inputs App, Funder Dashboard and Fresh Product Marketplace	- Khula App (Pty) Ltd - AECI Ltd - E-Squared Investments	Khula provides small-scale and commercial farmers with software, a product marketplace, and an institutional funding platform. Launched in 2019, the company has signed up more than 3,000 farmers, and over 100 suppliers now work with the company.
Lula mobility platform	- Lula Loop (Pty) Ltd	Mobility platform that provides a transport service for businesses and private clients, connecting corporate commuters to safe, affordable, and sustainable shuttles.
MALII smart mobility platform	- MALII Fintech - SAB Foundation - Rand Merchant Investments	MALII is an app that enables taxi commuters to make payments without using cash. Currently being piloted in Gauteng province with plans to scale nationwide. It addresses the cash payment system, financial exclusion, and inefficiencies in the minibus taxi industry.
Medsol Breast AI	- Medsol AI Solutions - SAB Foundation	Online patient-based platform that receives images for ultrasound units in practice. Software designed for breast cancer identification and segmentation for breast ultrasound in the diagnostic imaging sector using Deep Machine Learning and Artificial Intelligence. Received funding in 2021 from SAB foundation.

TECHNOLOGY	KEY SOUTH AFRICAN ACTOR	DESCRIPTION
Point of sale card machines and payment gateway	- Yoco Technologies - Dragoneer Investment Group	Point of sale applications, payment gateway and card machines providing access to offline payments for small and independent businesses. Yoco was founded in 2013 and has raised $102 million in financing since inception.
Smart Distribution Network System (SDNS)	- University of Johannesburg	Smart Distribution Network System to control and manage energy usage from the consumption side. Digitalised electrical network concept that allows the existing power network to operate at an optimum level during peak periods and limits unnecessary consumption excesses. Simulation tests have been conducted.
SwiftVEE mobile app	- SwiftVEE - Google Launchpad - Subtropico Limited	Online auction platform enabling the buying and selling of livestock products where farmers can register and make bids online or watch live online auction video streams. Developed by start-up SwiftVEE which was founded in 2017. Currently the largest independent livestock trading platform.
Syked Online Mental Wellness services	-- Syked - HaloCare Disease Management - SAB Foundation	Online wellness platform that connects clients to a network of vetted and qualified therapists via video call, text and telephonic support. Awarded grant funding and mentorship support from SAB Foundation in 2020.
uYilo eMobility Programme	- Nelson Mandela University - Global Sustainable Mobility Partnership - Technology Innovation Agency	The national uYilo Electric Mobility Programme was established in 2013 as an initiative of the Technology Innovation Agency to enable, facilitate and mobilise electric mobility. Services include the uYilo 'Kick Start' fund, established to support local industry-related projects that can be commercialised to advance localisation of the South African eMobility industry.
Web-based legal services	- Keakopa - Consumatech	Web-based solution that allows users to create simple contracts when lending money to friends and family. Also supports debt recovery services. Developed by Keakopa, supported by Consumatech.

IMPORTANCE OF THIS TECHNOLOGY FOR SOUTH AFRICA'S DEVELOPMENT

- DCDT Minister Khumbudzo Ntshavheni has declared the government's intention to position South Africa as the continent's e-commerce and digital hub (Ntshavheni, 2022).
- Constributes to the National Development Plan's Vision 2030 – knowledge economy, job creation, digital economy and e-commerce.
- Goga (2021) summarises the potential benefits for South Africa's growth as threefold. Increasing opportunities for South African firms in external markets, job creation through greater economic activity, and greater economic inclusion through trading.

PUBLIC SECTOR ACTORS	PRIVATE SECTOR ACTORS	OTHERS
Broadband Infraco	AgriKool	AECI Ltd
South African Medical Research Council	Mellowcabs	Dragoneer Investment Group
South African Post Office	Gknowmix	E-Squared Investments
University of Johannesburg	Khula App	Partech
Payments Association of South Africa	Lula Loop	Rand Merchant Investments
Department of Communications and Digital Technologies	MALII Fintech	SAB Foundation
	Yoco Technologies	Subtropico
	Medsol AI Solutions	Velocity Capital Fintech Ventures

POLICY SUPPORT

The Department of Communications and Digital Technologies (DCDT) is mandated "to lead South Africa's digital transformation" and is responsible for creating a policy and regulatory environment that centres on digital inclusion and inclusive development in economic growth (GCIS, 2021). The South African government responded early to the opportunities that e-commerce presented. The then Department of Communications published a first White Paper, "Discussion Paper on Electronic Commerce Policy", in 1999 followed by "A Green Paper on Electronic Commerce for South Africa" in November 2000. Policy questions then were decidedly apposite: focusing on security and privacy issues, standardisation, infrastructure, and inclusion (Department of Communications, 2000). Although a raft of new legislation has been introduced to complement existing laws and regulations, e-commerce policy has since been subsumed within the broader digital economy. The draft "Digital Economy Master Plan" was finalised in mid-2021, beginning a round of stakeholder engagement focused on developing an implementation plan (GCIS, 2021).

However, the prioritisation and levels of support for e-commerce within this broader digital economy has yet to be clarified. Efforts are being made to bolster logistics by expanding the offerings of the South Africa Post Office as a digital hub and e-commerce services provider. Conversely, policies pertaining to taxation and international competitiveness arguably disincentive trade. E-commerce trade may be subject to higher levels of taxation as certain categories of goods attract additional taxes and duties, while the threshold for VAT at R50 000 for Foreign Electronic Service Entities is significantly low (Goga and Paelo, 2019).

There are three main policies that appear to promote E-commerce in South Africa:

- SA Connect 2013, South Africa's broadband policy aimed to ensure 100% connectivity to broadband by 2030 through the development of policy and incentives.
- The National Electronic Media Institute of South Africa has had its mandate expanded to develop South Africa's e-skills capacity.
- The South African Post Office Amendment Bill, published for public comment in April 2022, seeks to expand the offerings of this utility, including providing for logistics and e-commerce services and to serve as a logistics partner.

There appears to be a single policy that regulates e-commerce in South Africa:

- Amendments to the Value Added Tax Act of 1991 requires all Foreign Electronic Service Entities to register for VAT when value traded exceeds R50 000.

FUNDING

There is limited information on funding for e-commerce businesses and transactions, and our desk review found that where publicised these were often confidential. The online stores that dominate that market are owned by large corporates and are likely better able to leverage resources and attract funding. Smaller companies, in contrast, would have to rely on venture capital funders and grant funding for early capital injections. Notable investments include Yoco Technologies which raised a $83 million in 2021 – the largest partially disclosed funding transaction in our study. Smaller transactions include Khula App (Pty) Ltd, awarded US$1.3 million seed round funding to scale its operations circa 2021, while online B2B auctioneer Swiftvee was awarded US$1.5 million in 2020 to facilitate their expansion into southern Africa. Several VC firms include the South African e-commerce industry within their remit, including Naspers, which owns 96% of the leading online retail platform Takealot.com.

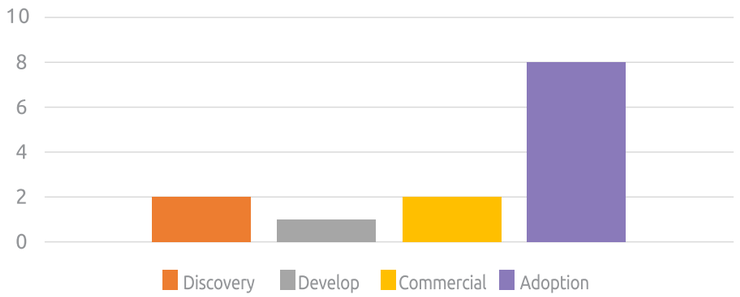
VENTURE CAPITALIST FIRM	INVESTMENT RANGE
Goodwell Investments	$500K - $2M; seed stage
Knife Capital	$50K - $1M; seed stage
MEST	$50K - $200K; seed stage
Naspers	Not disclosed; series B
Newtown Partners	$500K - $5M; seed stage

Source: *Extracted from Starterstory.com (2022), Tracxn.com (2022)*

STAGE OF DEVELOPMENT

While firms engaged in earlier stages of technology development are less visible, our desktop review revealed several firms well underway in their transition from commercialisation to adoption. Notable B2B examples in agriculture are AgriKool, which has developed a platform for smallholder farmers to source market linkages and financing opportunities, and Khula App (Pty) Ltd, whose software tools include marketing and trade platforms for farmers. Innovations for the transport sector include MALII Fintech's app enabling taxi commuters to make payments for taxi services without using cash and Lula Loop's platform connecting customers to private shuttle services. In the health sector, B2B e-commerce technologies include Medsol AI Solutions, providing breast imaging services, and Gnowmix, which offers genetic testing services. The relative maturity of the technology globally and its widespread acceptance may account for the relatively rapid pace at which new firms are able to bring novel iterations to market. For example, Khula App (Pty) Ltd, incorporated in 2018, came to market only a few years later and was able to attract funding to support diffusion in 2021.

The pace at which new entrants are able to move through development may suggest fewer bottlenecks at later stages. Known barriers include logistics which is key in e-commerce trade. Here, the challenges facing the South African Post Office utility are widely known; ongoing backlogs have likely stifled the market, forcing companies to rely on costlier private courier services (Goga, 2021). For smaller firms looking to develop retail e-commerce technologies, barriers such as access to finance, poor infrastructure, skills shortages, high transactions cost and low levels of research and development have been identified, likely impacting both development and commercialisation stages (Mkhosi, 2017). Banking and transaction costs are of particular concern for smaller firms (Goga, Paelo and Nyamwena, 2019), while firms seeking to expand to external markets also face exchange rate volatility and high costs for international transactions (Mkhosi, 2017).



Identifying barriers at each stage of development has proven difficult. However, reflecting the opportunities for further growth in the e-commerce market in South Africa, including market size, new entrants and new platforms, the challenges facing the industry are well-studied. Goga (2021) notes the high cost of data relative to other countries, which cannot but hinder the growth of the digital economy and, by extension, the e-commerce market. As discussed above, the legacy challenges of the South Africa Post Office are also raised as a limiting factor (Goga, 2021), necessitating alternative logistics infrastructure and new policy commitments by government to keep pace with e-commerce demands. Another critical structural challenge is access to electricity – ongoing load shedding at the power utility Eskom has curtailed business operating hours. Issues cited by consumers include high delivery fees, unreliable delivery times, and cumbersome returns (Schaefer and Bulbulia, 2021), while product, privacy and security risks are found to be key factors inhibiting online shopping (Makhitha and Ngobeni, 2021). However, as Eden et al. (2021) and others conclude, there are opportunities for increased market penetration across all products and services if challenges and obstacles are addressed.

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DEEP DIVE 5: NON-DIGITAL TECHNOLOGIES – WATER PURIFICATION

This deep dive focuses on a technology area that includes non-digital and at times, less high-tech solutions. Such solutions appear to receive the least focus in the emerging technology landscape in South Africa, but often address key development problems faced by the country. For example, in the case of water purification, according to Stats SA, 89.1% of South Africans have access to water (StatsSA, 2021) however this differs significantly between provinces and even for those with access to improved water sources, more than 40% have some issues with this access while 20% had significant challenges to this access (Mudombi, 2020). There are also approximately 837 000 households in South Africa that obtain their water from flowing water (streams and rivers), stagnant water (pools and dams), communal boreholes, wells and springs (StatsSA, 2020).

This study identified the following projects involving water purification technologies in South Africa:

TECHNOLOGY	KEY SOUTH AFRICAN ACTOR	DESCRIPTION
Autonomous water purification system	- Advance Call (Pty) Ltd - Council for Scientific and Industrial Research - Stellenbosch University - Tshwane University of Technology - Virtual Consulting Engineers (Pty) Ltd - CONDIAS GmbH - Fraunhofer IST - University of Castilla La Mancha - University of Ferrara	The SafeWaterAfrica project aimed to develop, introduce and apply a new and autonomous water purification system using adapted European low energy water treatment technology.
Acid mine water treatment	- Roc Water Technologies (Pty) - Climate Innovation Centre South Africa - Water Research Commission	Roc Water Technologies has developed a unique, low-cost solution to produce drinking water and other valuable products from acid mine water. In 2019, the company raised R2.7 million from the Water Research Commission to demonstrate the technology at scale.
Water purification microfilter	- VulAmanz Water Filters - Technology Innovation Agency	Water purification microfilter that utilises a locally produced woven polyester microfiltration membrane. Currently seeking to pilot at scale.

Other projects identified in this study related to water purification include water filtration and treatment systems using nanotechnology equipped with Internet of Things technology developed by Kusini Water. These projects entail digital technologies, while the focus of this section is non-digital technologies.

ACTORS

The main actors in this space are the Department of Water and Sanitation, the Water Research Commission and various universities. There are also actors in the private sector as noted in the following table:

PUBLIC SECTOR ACTORS	PRIVATE SECTOR ACTORS
Department of Water and Sanitation Academy of Science of South Africa (ASSAf) Council for Scientific and Industrial Research (CSIR) Durban University of Technology National Research Foundation (NRF) Stellenbosch University Tshwane University of Technology (South Africa) Water Research Commission (WRC) Technology Innovation Agency (TIA)	Advance Call CONDIAS GmbH Kusini Water Roc Water Technologies VulAmanz Water Filters

Government plays an important role in funding research in this area. Agencies such as the Water Research Council, CSIR and the Department of Water and Sanitation and the National Research Fund (NRF) are involved in the funding of research and development of water purification technologies. These fund research through higher education institutions and private companies involved in developing emerging technologies, according to Interviewee 14. Furthermore, it is reported that R&D expenditure on water supply (including electricity and gas) amounted to R7.6 million in 2019/2020 (CeSTII).

Research is mostly conducted by higher education institutions including Stellenbosch University (SU), Tshwane University of Technology (TUT) and Durban University of Technology (DUT). The Durban University of Technology was awarded a South African Research Chair in the Institute for Water and Wastewater Technology, to ensure access to water and sanitation for all.

The private sector is also taking an interest in the development of water purification technologies. These include companies such as AdvaceCall and CONDIAS GmbH who are key partners in the EU-funded SafeWaterAfrica programme, implementing novel water purification systems in South Africa. The European-African alliance developed a novel water-cleaning system under the SafeWaterAfrica project. The system purifies contaminants and removes pathogens, resulting in clean and safe drinking water for rural communities. This system was successfully tested in South Africa and other African countries and the total cost of the project was approximately €3 million (R50 million) (SafeWaterAfrica, 2022). Other local companies include Kusini Water, who manufacture and assemble water filtration and treatment systems and VulAmanz who, with the support of TIA, have developed a water purification filter utilising a locally woven microfiltration system.

FUNDING AND INVESTMENTS

As noted above, the funding agencies, Technology Innovation Agency and Water Research Commission, are most visible in this space. Notable investments in the last couple of years include R2.7 million, received by Roc Water from WRC.

POLICY SUPPORT

The following policies are used to promote, regulate and incentivise work in South Africa and at regional level in the area of water purification.

PROMOTE	REGULATE	INCENTIVISE
Constitution of the Republic of South Africa (Bill of Rights)	- SANS 241 specifies the quality of acceptable drinking water, defined in terms of microbiological, physical, aesthetic and chemical determinands. - National Environmental Management Act 107 of 1998 (NEMA) - National Water Act 36 of 1998 - Water Supply and Sanitation Policy White Paper (1994)	Blue Drop Certification Green Drop Certification

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