Technology Needs Assessment - Rwanda

Republic of Rwanda

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Acronyms and Abbreviations

AfDB	African Development Bank
AI	Artificial Intelligence
AIMS-NEI	African Institute of Mathematical Sciences - Next Einstein Initiative
ALU	Africa Leadership University, Rwanda
AUCA	Adventist University of Central Africa, Kigali
BNR	National Bank of Rwanda
BRD	Rwanda Development Bank
Cc HUB	Co-Creation Hub
CMU-Africa	Carnegie Mellon University-Africa
CoK	City of Kigali
CST	College of Science and Technology, UR
DBF	Business Development Fund
FCDO	Development Office (FCDO), United Kingdom (UK)
DFID	Department for International Development. Now called Foreign, Commonwealth and Development Office
EAC	East African Community
EASTECO	East African Science and Technology Commission
ECJRC	European Commission, Joint Research Centre
ERF	Economic Recovery Fund, Rwanda
EU	European Union
FabLab	Fabrication Laboratory, Rwanda
FCDO	Foreign, Commonwealth and Development Office, UK
FDI	Foreign Direct Investment
FONERWA	Rwanda Green Fund
GIS	Geographic Information System
GIZ	German development agency
GoR	Government of Rwanda
GO-SPIN	Global Observatory of Science, Technology and Innovation Policy Instruments, UNESCO
GSMA	Global System for Mobile Association
HEC	Higher Education Council
HLIs	Higher Learning Institutions
ICT	Information and Communication Technology
INES	Institut d'Enseignement Supérieur de Ruhengeri
IoT	Internet of Things
IPR	Intellectual Property Rights
IPRC	Integrated Polytechnic Regional College (IPRC), Kigali, RP
JICA	Japan International Cooperation Agency
KCRC	Kigali Collaborative Research Centre
KFW	German state-owned investment development bank
kLab	Kigali Laboratory
KOICA	Korea International Cooperation Agency
MCA	Multi-Criteria Analysis methodology
MFIs	Microfinance Institutions
MICE	Meetings, incentives, conferences, and exhibitions
MINAGRI	Ministry of Agriculture and Animal Resources
MINECOFIN	Ministry of Finance and Economic Planning

MINEDUC	Ministry of Education
MINICOM	Ministry of Trade and Industry
MINICT	Ministry of ICT and Innovation
MoH	Ministry of Health
NAEB	National Agricultural Export Development Board
NCST	National Council for Science and Technology
NIRDA	National Industrial Research and Development Agency
NISR	National Institute of Statistics of Rwanda
PSF	Private Sector Federation
RAB	Rwanda Agriculture and Animal Resources Board
RBC	Rwanda Biomedical Centre
RCA	Rwanda Coding Academy
RDB	Rwanda Development Board
REG	Rwanda Energy Group
RICA	Rwanda Institute for Conservation Agriculture
RIF	Rwanda Innovation Fund
RISA	National Information Society Authority
RMB	Rwanda Mines, Petroleum and Gas Board
RP	Rwanda Polytechnic
RRA	Rwanda Revenue Authority
RSB	Rwanda Standards Board
RTB	Rwanda TVET Board
RURA	Rwanda Utilities and Regulatory Agency
S3	Smart Specialisation Strategy
SACCOs	Savings and Credit Cooperative Organisations
SDGC/A	Sustainable Development Goals Center for Africa
SDGs	Sustainable Development Goals
SETI	Science, Engineering, Technology, and Innovation
SGCs	Science Granting Councils
SIDA	Swedish International Development Agency
SJR	Scimago Journal & Country Rank
SMEs	Small and medium-sized enterprises
SSA	Sub-Saharan Africa
STIP	Science, Technology, and Innovation Policy
TBLDC	[United Nations] Technology Bank for the Least Developed Countries
TSC	Technology Support Centre, Rwanda
UAVs	Unmanned aerial vehicles (drones)
UGHE	University of Global Health Equity
UIS	UNESCO Institute of Statistics
ULK	Kigali Independent University, Polytechnic Institute
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNIATTST	United Nations Inter-Agency Task Team, Science Technology
UoK	University of Kigali (UoK)
UR	University of Rwanda
USAID	United States Agency for International Development
UTAB	University of Technology and Arts of Byumba

UTB	University of Tourism Technology and Business Studies
VNR	Voluntary National Review report on SDGs
WASAC	Water and Sanitation Corporation, Rwanda
WB	World Bank
WIPO	World Intellectual Property Organisation

Table of Contents

List of Figures

List of Boxes

List of Tables

1 According to BNR; Large corporate is a business with annual turnover above RWF 500 million (M); SME is a business with annual turnover ranging between FRW 20M and 500M; and Micro business is a business with annual turnover less than RWF 20M. Informal microbusinesses were eligible to access ERF through Micro business (MFIs) window subject to demonstrating proof of local tax payment.

2 May be revised to include the Global Science Supply and Global Technology and Innovation Supply, as part of International STI Supply. Reference to Fig 3.2 (pg.47) of Guidebook on STI for SDG Roadmap

Foreword

The significance of technology and innovation as essential drivers for productivity and economic growth in developing nations is widely acknowledged. In the case of Rwanda, science, technology and innovation serve as fundamental pillars of its vision to evolve into a knowledge-based economy.

This strategic orientation is crucial for achieving the country's national aspirations and meeting the developmental objectives outlined in the 2030 Agenda. Thoughtful, strategic, and substantial investments in key technological solutions, as well as targeted investment in innovation capacities, can accelerate the path to sustainable structural transformation for Rwanda, and expedite the country's progress in various sectors, contributing to its long-term economic growth.

In pursuit of this vision, the Ministry of ICT and Innovation has collaborated with the United Nations Technology Bank for the Least Developed Countries to produce this Science, Technology and Innovation Review and Technological Needs Assessment. This report is designed to provide valuable insights and guidance for the technological advancement process of Rwanda's priority sectors. It also aims at ensuring that the country is well equipped and positioned to fully engage in the Fourth Industrial Revolution, and future technological development is inclusive and genuine. Digital and other cutting-edge technologies will play pivotal roles in the growth of industry and services, as well as the modernization and commercialization of agriculture. Notably, the report's findings closely align with the science, technology, and innovation (STI) policies and strategies of the Rwandan government, offering a clear roadmap for reinforcing STI development in key sectors such as agriculture and manufacturing.

This TNA also builds upon the untapped economic potential of the country's youth in the fields of science, technology, and innovation, reflected in; their active engagement in the digital economy, as well as in fostering the entrepreneurial landscape through incubator and acceleration hubs that are being established in the country.

The innovative insights presented in this report serve as an invaluable resource and a practical tool for Rwanda to actively engage with hope and energy in contributing to Agenda 2030 and bettering the quality of life of its people. Furthermore, the knowledge and experiences shared in this report are relevant and applicable to other LDCs across Africa, Asia, and Central America, and in that sense provides as a learning tool beyond the country.

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Executive Summary

Introduction and Background

This report presents the Science Technology and Innovation (STI) review and Technology Needs Assessment (TNA) for the Republic of Rwanda conducted by the United Nations Technology Bank for Least Developed Countries (Technology Bank) in close collaboration with the Rwandan Ministry of ICT and Innovation (MINICT).

The overarching objective of the UN Technology Bank is to help the least developed countries build the STI capacity that they need to promote the structural transformation of their economies, eradicate poverty, and foster sustainable development. Its specific objectives as outlined in its Charter are to:

- Strengthen the STI capacity of least developed countries, including the capacity to identify, absorb, develop, integrate and scale-up the deployment of technologies and innovations, including indigenous ones, as well as the capacity to address and manage Intellectual Property Rights issues;
- Promote the development and implementation of national and regional STI strategies;
- Strengthen partnerships among STI-related public entities and with the private sector;
- Promote cooperation among all stakeholders involved in STI, including, researchers, research institutions, public entities within and between LDCs, as well as with their counterparts in other countries;
- Promote and facilitate the identification, utilisation, and access of appropriate technologies by least developed countries, as well as their transfer, while respecting intellectual property rights and fostering the national and regional capacity of least developed countries for the effective utilisation of technology in order to bring about transformative change.

The TNA in Rwanda: goals and objectives

Informed by the Rwanda National Strategy for Transformation (NST1 2017-2024) and Vision 2050, and reflected in the STIP, the objectives of the TNA in Rwanda are to:

1. Offer knowledge contribution to the understanding of the role of technology in Rwanda's STI system, and for achieving the country's socio-economic transformation and SDGs.
2. Identify and analyse technologies that could underpin and facilitate attainment of Rwanda's 2050 development agenda across priority sectors including: energy, agriculture, health, manufacturing, ICT and innovation, and environment, alongside cross-cutting areas such as gender, education, financial services, and infrastructure. This TNA focus on agriculture and
3. Deepen understanding of the capability needs[1] to enable effective development, adaptation and use technology. And thus, allow Rwanda to leapfrog, enhance competitiveness, and become a leader in specific technologies in identified priority sectors.
4. Identify avenues for complementarity of home-grown technologies with imported technology, to create the desired sustainable local technology capacity and capability base, particularly in support to the implementation of 'made-in-Rwanda' policy.
5. Propose approaches to create and/or foster interactions amongst technology stakeholders to enhance the sustainable development, commercialisation, and diffusion of technologies in priority sectors of Rwanda STI system.

1 At individual/human, institutional and systems levels

Methodology and Guiding Frameworks

The methodology for the TNA involved a co-creation process of active participation, data and information gathering from relevant stakeholders in Rwanda through well-defined focused group meetings, workshops, and expert interviews. The specific steps in the data collection for the STI Review and TNA involved Focused Group Discussions (FDGs), meetings and three (3) separate workshops with 15-20 participants in each workshop. The specific steps in the methodology are as follows:

- Workshop 1 and FGDs: Key technology and innovation actors and stakeholders from sectors outlined in Section 2.3: Energy, Agriculture, Health, manufacturing, ICT and Innovation, Environment and Cross-cutting themes.
- Workshop 2 and FGDs: Stakeholders from Agriculture sector.
- Workshop 3 and FGDs: Stakeholders from Manufacturing sector.
- Expert interviews: The workshops findings were complimented with insights from targeted expert interviews, conducted in the months of July and August 2021.
- Workshop 4 and FGDs: Validation meeting with broad STI and development stakeholders from Rwanda and beyond.

Results of the TNA are discussed in the sections below, starting with the key messages that emerged from the data.

Key messages

1. **Technologies are needed to help unlock the long-term transformative change and development impacts that could result from the agricultural sector in Rwanda.** From pre-cultivation through cultivation to post-cultivation, and in livestock farming; technologies are needed across the agriculture value chain, if the sector is going to achieve the development aspirations, goals and objectives articulated in the national Vision 2050 and sectoral policies such as the Strategic Plan for Agriculture Transformation 2018-2024 and ICT strategy for Rwanda Agriculture (ICT4RAg).

   Critical areas of technology need in Agriculture range from technologies to 1) enhance productivity in farm operations such as Greenhouses, Biodigesters, Drones, AI and IoT; and 2) process, store, and transport produce, such as Refrigeration and Robotics; to 3) enable data, information and knowledge gathering and sharing, such as smart/mobile phones and platform technologies. Weaknesses in technology mean that Agricultural productivities continue to be hindered. Addressing the gaps in technologies for agriculture will support Rwanda's ambition of moving into the middle-income country status, contribute poverty reduction and the realisation of Vision 2050 and the SDGs.
2. **Rwanda desperately needs an Advanced Manufacturing sector driven by technologies.** Technologies are essential to realising this ambition, both for the wider economy and for the specifics outlined in policies such as "Made in Rwanda". Evidence presented in Section 4 show that the Manufacturing sector is currently the third largest contributor to Rwanda's GDP, following Agriculture, with Service sector in lead. Despite this position as the second top contributor to Rwanda's GDP; the discussions on TNA Priority 1, Agriculture sector, point to the untapped potentials for the Manufacturing sector. A strengthened manufacturing sector will support progress in agriculture and other sectors. Advancements in the manufacturing sector is essential to addressing many of the challenges identified in the agricultural sector, including processing, storage, refrigeration, and value addition to raw materials, for example in textiles. Effective deployment of technologies in the manufacturing sector will help position Rwanda as the manufacturing hub for the region.

3. **To realise the full potentials of technologies in the national development agenda, Rwanda must expand the understanding of technology beyond Information and Communication Technologies (ICTs).** The government of Rwanda has made significant progress in ICTs. However, while the role of technologies in information[2] and communication was recognised as important to progress in Agriculture, the majority of the technologies identified as critical to productivity increases or in manufacturing sector extend beyond ICTs. Consequently, to fully exploit advanced and emerging technologies in manufacturing, agriculture, and others[3], it is vital that the focus and emphasis shifts to technologies over and beyond ICTs to include those discussed in this report.
4. **Robust cross-cutting and sector-specific policies and strategic interventions on technology development, adaptation, diffusion, absorption, and utilisation are paramount** if Rwanda is to achieve the aspired vision of becoming upper middle-income country by 2035 and higher income country by 2050. Existing national policies, such as the Made in Rwanda policy do not go far enough. Sector-specific policies are, for example, needed to address the gaps in standardisation, quality control and traceability – all of which are essential for boosting export and enhancing competitiveness. Considering Rwanda's policy of being a 'proof of concept state' for imported technologies and innovation; it is important to ensure that each sector specific technology policy and/or intervention in Rwanda is effectively contributing to the value chains of imported technologies (and/or innovations). This is vital, if Rwanda is going to leapfrog and become a leader in these technologies.
5. **Policy formulations are important, but they are not, in themselves, sufficient to bring about the long-term transformative change required to move Rwanda to the next levels of development.** Rather, policy formulation must be accompanied by effective implementation, alongside monitoring, evaluation, and interactive learning among actors and stakeholders. To achieve effective implementation, other ingredients are essential. These ingredients include carefully designed (technology, science, and innovation) policy instruments, strengthening of capabilities and skills, availability of funding, and commitment by key actors and stakeholders. Furthermore, implementation must be, where applicable, supported by experimentation on the part of implementing actors, coupled with reflexivity by policymakers. Experimentation would enable implementing actors to 1) try different approaches, 2) learn what works, in what contexts, and under what conditions, and 3) adapt where necessary. For example, farmer-led experimentation on what works in practice at community levels may provide vital lessons on ways to increase productivity, reduce environmental degradation and climate change impacts, or address social challenges such as inequalities and exclusion. Similarly, experimentation at policy levels, that is policy experiments, would help policymakers deepen understanding of new approaches to policymaking that provides that optimises the prospects of implementation and development impacts.

Summary of Recommendations for Rwanda's Main NSI Stakeholders

We present some of the recommendations below. The complete list of recommendations is provided in Section 7.2

The Government of Rwanda and Development Partners

1. Address gaps in the governance of the NSI as a way of enhancing the implementation prospects of the findings, the STI policy and other related policies. Establish a Technology Governance Board (TGB) – made up of members from the NSI – with oversight functions, to help ensure a good governance structure and effective implementation of the recommendations, programmes, and projects. To achieve the desired outcomes as proposed in this report, the TGB should function across sectors but also with a specific lens on agriculture and manufacturing, whenever relevant.

2 Gathering and knowledge sharing e.g. among farmers

3 Including Energy, Pharmaceutical, and Education not discussed in detail in this report

2. Emphasize effective implementation of the findings; and support the deployment of technology across board, alongside the development of appropriate policy mix, strengthening capabilities and skills, and a focus on the SDGs.
3. Improve access to technologies, especially for women and other marginalized groups, by ensuring affordability. And ensure that specific policies, programmes, and projects are put in place to address gender issues with respect to the technology solutions that have been recommended.

Academia

1. Re/Focus research, teaching and learning on addressing the gaps in the STI systems with a view to ensuring that STI effectively contributes to tackling Rwanda's development challenges as articulated in the national Vision 2050.
2. Strengthen capabilities, skills and human capital in innovation, STEM and public policies and policymaking. To achieve this objective, it may be necessary to update the relevant teaching methods and learning practices and curricula on research, innovation, STEM, and digital to the appropriate international standards necessary to placing Rwanda on a world-class status.
3. Strengthen linkages with other NSI actors, especially government, where such linkages exist; and create new linkages where they currently do not exist. Innovation is systemic and is fostered in the atmosphere of interactive learning. Therefore, interactions, learning and effective collaboration with other NSI actors and stakeholders is essential to realising the objectives outlined.

Industry – large, medium, and small (e.g., technology start-ups)

1. For large and medium industry actors, especially; set up dedicated R&D and technology development units, funding streams, policy instruments, and incentives that promote science and innovation, technology development, diffusion, deployment, utilisation, and application in Rwanda.
2. Improve collaborations on technology, R&D, innovation, and capabilities strengthening with NSI actors and stakeholders. Effective collaboration among actors is essential to innovation and improves the prospects of technology development, commercialisation, adoption, and utilisation.
3. Contribute to improving Rwanda's innovation status by refocusing attention on increasing the numbers of domestic technology and innovation outputs, patents, innovation and technology hubs, and support for start-ups and grassroots innovators.

Civil Society Organisations (CSOs), Innovation Intermediaries, and Service Providers

1. Design and implement technology, science and innovation public engagement events, promotion activities and awareness campaigns with a view to helping NSI actors establish programmes, projects and policy measures that help mainstream technology as an essential input to economic growth and sustainable development.
2. Strengthen the case for increased participation and representation of women and girls in research, STI and STEM. And support NSI actors in capabilities and skills building, and infrastructure development in STI, especially with respect to gender divides and inequality in STEM.
3. Work with NSI actors – especially government, academia, and industry (Triple Helix actors) – in expanding technology, science and innovation opportunities, programmes and projects in ways that help focus greater attention on inclusivity and the SDGs.

Recommendations for Agriculture and Manufacturing Sectors

1. Constitute R&D units in industries. R&D units are essential as markets are dynamic, particularly in agro-processing sub-sector. For example, engagement in R&D explains in part why some firms can introduce diversified products to the markets, while other firms are not so successful in this regard.
2. Deepen understanding and capabilities on (digital) technologies and embrace digitalisation.
3. Develop and implement policies and regulations that foster adoption of standards and quality management systems.
4. Strengthening innovation and manufacturing capabilities through education and specialized skills development.
5. Revise and update existing curricula or create new curricula where applicable; focus on learning.

CHAPTER 1
Introduction

Rwanda is committed to fostering innovation and entrepreneurship, as a key pillar for transforming our country and our continent, both socially and economically. We are already seeing some of the benefits, not to mention the even bigger potential that lies ahead. The use of drones to deliver life-saving blood products and vaccines to remote health centres, is already a reality in Rwanda, through our partnership with Zipline. A Rwandan company, Charis UAS, is using drone technology for crop monitoring and mapping, to support the productivity of our farmers. Another application already in use, is the inspection of power transmission lines from the air, to help make our electricity grid more reliable. There is also a pilot project to test the effectiveness of drones for mosquito spraying. There is so much that can be done with this technology, investment in physical infrastructure and human capital, should go hand-in-hand with the adoption of drone technology.

H.E. Paul KAGAME,
President of the Republic of Rwanda, The Africa Drone Forum, Kigali,
5 February, 2020[1]

1.1 Background to the Technology Needs Assessment Process

The status of Science Technology and Innovation (STI) ecosystem in Rwanda, discussed in detail in Section 3, indicates a high-level support for STI by the government – as expressed in relevant policies and regulations. Nevertheless, weaknesses remain, which include the governance of STI and coordination of STI actors, low research, knowledge, and technology outputs, which are essential for socioeconomic development. To help addresses gaps and exploit opportunities identified, this report presents the STI review and Technology Needs Assessment (TNA) for the Republic of Rwanda. The study was conducted by the United Nations Technology Bank for Least Developed Countries (Technology Bank) in collaboration with the Rwandan Ministry of ICT and Innovation (MINICT).

The overarching objective of the Technology Bank is to help the least developed countries build the STI capacity that they need to promote the structural transformation of their economies, eradicate poverty, and foster sustainable development. Its specific objectives, as outlined in its Charter, are to:

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- Promote the development and implementation of national and regional STI strategies;
- Strengthen partnerships among STI-related public entities and with the private sector;
- Promote cooperation among all stakeholders involved in STI, including, researchers, research institutions, public entities within and between LDCs, as well as with their counterparts in other countries;
- Promote and facilitate the identification, utilisation, and access of appropriate technologies by least developed countries, as well as their transfer, while respecting intellectual property rights and fostering the national and regional capacity of least developed countries for the effective utilisation of technology in order to bring about transformative change.

1.2 The TNA in Rwanda: goals and objectives

Informed by the Rwanda National Strategy for Transformation (NST1 2017-2024) and Vision 2050, and reflected in the STIP, the objectives of the TNA in Rwanda are to:

1. Offer knowledge contribution to understanding the role and locus of technology in Rwanda's STI system, and for achieving the country's socio-economic transformation and SDGs.

1 President Kagame's Remarks at the African Drone Forum, Kigali, 5 February 2020, https://www.paulkagame.com/president-kagames-remarks-at-the-african-drone-forum-kigali-5-february-2020/

2. Identify and analyse technologies that could underpin and facilitate attainment of Rwanda's 2050 development agenda across priority sectors including: energy, agriculture, health, manufacturing, ICT and innovation, and environment, alongside cross-cutting areas such as gender, education, financial services, and infrastructure.
3. Deepen understanding of the capability needs[2] to enable effective development, adaptation and use technology. And thus, allow Rwanda to leapfrog, enhance competitiveness, and become a leader in specific technologies in identified priority sectors.
4. Identify avenues for complementarity of home-grown technologies with imported technology[3], to create the desired sustainable local technology capacity and capability base, particularly in support to the implementation of 'made-in-Rwanda' policy.
5. Propose approaches to create and/or foster interactions amongst technology stakeholders to enhance the sustainable development, commercialisation, and diffusion of technologies in priority sectors of Rwanda STI system.

1.3 Methodology and Guiding Frameworks

The methodology for the TNA involved a co-creation process, systematic research, and data and information gathering from relevant stakeholders in Rwanda through well-defined focused group meetings, workshops, and expert interviews. This helped to ensure that the methodology and outputs are closely aligned to other national processes on-going or completed in Rwanda (Haselip et al., 2019, pp. 23–45). And in line with the national development agenda of the country (see Section 2 below). This report is the culmination of extensive data collection, analysis and stakeholder engagements with key actors involved via focused group discussions, workshops, and interviews (see Annex 2 and 3).

The methodology is guided by two frameworks: i) the National Systems of Innovation (NSI), which helps to understand and explain the roles of actors and stakeholders, and the ways that the interactions and learning among them shapes innovation (Freeman, 1987; Lundvall, 2010) and ii) Triple Helix (TH) of University-Government-Industry, which emphasises the importance of interactions among these stakeholders as a basis for fostering innovation (GoR, 2020b; Yongabo and Göransson, 2020; Yongabo, 2021a; Twiringiyimana et al., 2021[4]). In line with the NSI and TH frameworks, participants for the workshops, and interviews were selected because they are actively involved in the STI sectors identified as priority to Rwanda (GoR, 2020b)[5]. The Priority Sectors for Rwanda, based on the GoR Policy and Development plans[6] are energy, agriculture, health, manufacturing, ICT and innovation, and environment.

Criteria for Selecting the TNA Priority Sectors

The list below presents a set of criteria based on which stakeholders narrowed down the selection of the two priority sectors – Agriculture and Manufacturing – that formed the focus of this STI Review and TNA project. For a sector or sectors to be selected, it must:

1. Be outlined in the 2020 STI policy
2. Demonstrate a potential for high influence on other sectors
3. Be a sector(s) where technology can make the most transformative change and development impacts[7] in helping Rwanda achieve her transformation objectives

2 At individual/human, institutional and systems levels

3 A key consideration relates to improving understanding of the barriers that hinder home-grown technologies from being competitive when compared with imported technologies

4 These references are more specific to Triple Helix interactions in fostering innovation in Rwanda. For broader discussions on TH framework, see for example, Etzkowitz and Leydesdorff (2000), Etzkowitz and Dzisah (2008) and Daniels et al (2017).

5 See also Section 2.3 for detailed discussion on the priority sectors

6 Source: Rwanda STI Policy (GoR, 2020, p.23-26 – Section 5: Priority Sectors) https://www.ncst.gov.rw/fileadmin/user_upload/NCST/Publications/Policies/STI_POLICY_2020.pdf

7 Transformation and impacts from STI were discussed and agreed by stakeholders. In this sense, the focus on sectors where technology (including science and innovation), has a high potential of achieving economic growth while also addressing pressing social and development challenges confronting Rwanda.

4. Be in alignment to the long-term development agenda – Vision 2050 (and SDGs)
5. Be a sector(s) where Rwanda stands the best chance to attain a regional, continental (and possibly global) leadership position in technology (including science and innovation)

Based on the criteria outlined above, this STI Review and TNA focuses on two sectors, selected in consultation with stakeholders. The sectors, Agriculture and Manufacturing; and the link between the sectors are discussed further in the subsequent sections.

Operationalising the methodology

The specific steps undertaken in the STI review and TNA process include:

1. Virtual kick-off event with the national stakeholders. The objective was to present and discuss the STI review and TNA approach with identified stakeholders drawn from the priority sectors.
2. Desk review of available documents and data: identification of data and information sources and conducting document review and analysis. The review and data analysis covered academic and grey literature, databases, and other sources of information.
3. Virtual focus group meetings with key stakeholders: to gather data, for example on focal priority sectors, development needs, and key technologies; present and discuss the findings with stakeholders.
4. Targeted interviews with experts working on STI, development and policy. The interviews provided additional data to support the information gathered during the workshops.
5. Drafting of the STI review and TNA report.
6. Validation and dissemination of the final report at Virtual launching event.

Broad Stakeholders Workshop Summary – July 2021

The discussions focused on the six development priority sectors for Rwanda, as identified in the National STI Policy of 2020 (GoR, 2020b). As outlined above, the objective was to present and discuss the STI review and TNA approach with identified stakeholders drawn from the priority sectors. And to deepen our understanding of how the needs in the priority sectors may be addressed using technologies. From the six sectors there was consensus among stakeholders that the TNA should focus on **Agriculture** and **Manufacturing** as these present good opportunities for realizing Rwanda's transformation goals as articulated in the relevant government policies such as the Vision 2050 and STI policy. In addition, stakeholders agreed that although the TNA will focus on Agriculture and Manufacturing, other sectors – such as, health, energy, ICT and innovation and environment, alongside gender, finance[8] and education – will be treated as cross-cutting thematic areas. Taking this approach helps to improve the prospects of development impacts at systems level and connections to the SDGs.

Sector-specific workshops on Agriculture and Manufacturing

For the next step in the methodology, we organized two sector-specific workshops that focused on Agriculture and Manufacturing. Participants in the workshops, drawn primarily from the focus sectors of agriculture and manufacturing, include government, industry and academia, and other actors from the broader national system of innovation. The discussions helped to:

1. Dive deeper into the focus sectors and unpack the development needs, as expressed by stakeholders.
2. Examine possible technology solutions to help address the needs and harness the opportunities for transformation.
3. Identify and prioritize technologies that can adequately and effectively address the priority needs in both sectors, in line with cross-cutting themes encapsulated in the SDGs, such as gender, education, energy, and finance and services.
4. Identify barriers and challenges that hinder the deployment, diffusion, transfer, or acquisition of prioritized technologies in Rwanda.

8 Understood broadly to include mainstream finance instruments and institutions, fintechs or digital finance, and a focus on financial inclusion, particularly important for addressing the SDGs.

5. Evaluate the enabling environment (including policies, financing, capabilities and skills, research) for the utilization of the selected technologies.

In addition to the processes outlined above, this STI review and TNA drew on other existing STIP reviews and frameworks that are attuned to the SDGs (see Section 2.4). In particular, the STI review of Rwanda by UNCTAD (2017)[9] and the guidelines proposed in the Guidebook for the preparation of STI for SDGs Roadmaps (IATT and ECJRC, 2021, pp. 53–56). These reports were exploited to identify and categorise policy instruments for technology development, adoption, adaptation, diffusion, and use, in the context of Rwanda. This report has also applied ideas and concepts from UNCTAD's STI Policy (STIP) framework on policy instruments – categorised into 'regulatory, economic, fiscal, demand support, education etc – to strengthen the Rwanda's innovation and environmental sustainability (UNCTAD, 2019).

The UNCTAD framework also encourages 'co-creation and experimentation' (Matusiak et al., 2021, p. 38; Daniels et al., 2020; UNCTAD, 2020, p. 11). The UNCTAD STIP review framework[10] is aligned to the SDGs with respect to policy mixes and policy implementation. Other relevant STI review methodologies include i) the GO-SPIN[11] framework – emphasizing the 'need for policy instruments'– but limited to the analysis of 'existing of operational policy instruments' without developing them; ii) Transformative Innovation Policy (TIP) framework which focuses on policy implementation for transformation[12]; iii) and Smart Specialisation Strategy (S3) framework through which policy mix is predominantly developed by government authorities (Daniels et al., 2021; Matusiak et al., 2021).

1.4 The TNA in Rwanda: the use of the term "technology"

In conducting a TNA or Analysis, it is important to provide a brief explanation of how the term "technology" is used in the context of this study. The Government of Rwanda defines Technology as "the application of scientific knowledge to develop techniques to produce a product and deliver a service. Technologies are generally associated with manufacturing industries that constitute machines and devices that are in turn developed from technology"[13]. According to the Intergovernmental Panel on Climate Change (IPCC 2000), 'technology' is defined as 'a piece of equipment, technique, practical knowledge or skills for performing a particular activity'. Three components of technology are relevant in this regard: Hardware – tangible components (e.g., equipment and products); Software – processes associated with the production and use of the hardware. This includes a) Know-how (e.g. manuals and skills) and b) Experience and practices including technical, management and behavioural practices; and Orgware – institutional framework, or organisation, involved in the adaptation and diffusion process of a technology (Haselip et al., 2019, p. 9). We adopt these understandings of technology in the report.

9 STI Policy Review, Rwanda - https://unctad.org/system/files/official-document/dtlstict2017d8_en.pdf; https://unctad.org/system/files/non-official-document/enc162017p08_UNCTAD_STIP_Rwanda_en.pdf

10 "…provides a guide to the thinking that underpins the Science, Technology and Innovation Policy (STIP) Review programme of UNCTAD within the context of sustainable development and the 2030 Agenda. It has been written primarily for Member State governments that are considering or implementing STIP reviews as well as all those involved in UNCTAD intergovernmental mechanisms including the Commission on Science and Technology for Development (CSTD). It outlines… the methods and the various possible steps in the implementation process of STIP Reviews and their expected short- and medium-term outcomes" Source: https://www.un-ilibrary.org/content/books/9789210039697

11 UNESCO, *Global Observatory of Science, Technology and Innovation Policy Instruments*, https://gospin.unesco.org/frontend/home/index.php

12 With transformation defined in the broad sense, as addressing the SDGs

13 The Assessment of the State of Science, Technology and Innovation (STI) in Rwanda, National Council on Science and Technology (NCST), Rwanda (2021, p.12)

CHAPTER 2
An Overview of Rwanda: Background and Context

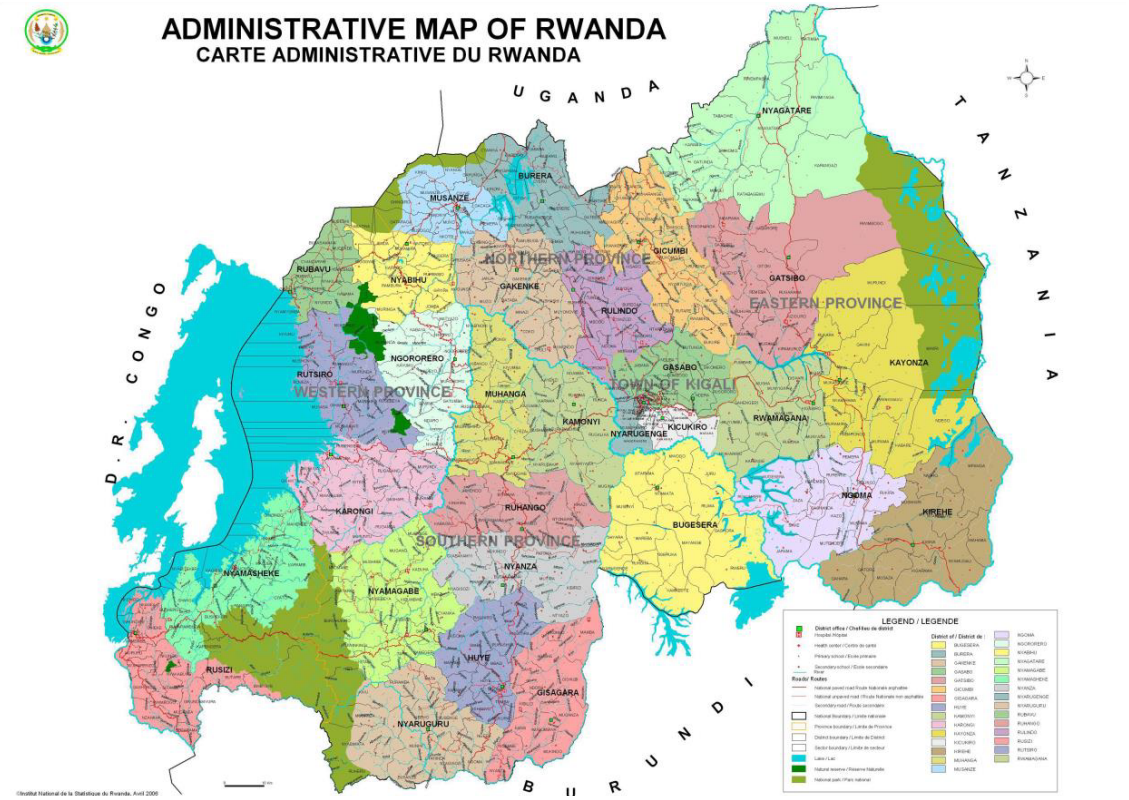


Figure 1: Administrative map of Rwanda. *Image credit: The National Institute of Statistics of Rwanda (NISR, 2008)*

Rwanda: An Overview

Rwanda is a small landlocked country with surface area of 26.3 thousand square kilometres. As illustrated in Fig1 above, Rwanda is surrounded by four countries: The United Republic of Tanzania in east, the Democratic Republic of Congo in west, Burundi in south and Uganda in north. According to the World Bank (WB)[1], Rwanda's population is 12.95 million, with population density (people per square kilometre of land area) of 498.7, making it the most density populated country in Africa, and with population growth rate of 2.5%. Under the leadership of President Paul Kagame, Rwanda's post 1994 genocide recovery and development agenda have been underpinned by relatively substantial investment in human capital development in science and technology, particularly in the information and communication technologies (ICTs). For instance, Rwanda has made significant investments in ICT infrastructure in the past decade, with about 7,000 kilometres of fibre optics cabling across all 30 districts of the country[2] (Box 1). Nevertheless, infrastructure needed to support relevant sectors remains at 25.6% (NCST, 2021).

This infrastructure has enabled rapid penetration of digital technologies with 76.5% of the population being subscribed to cellular mobile, and 21.8% of the population using internet[3]. Despite this high rate of coverage, factors such as capabilities and skills gaps and costs of data continue to limit the rate of use and adoption of digital technologies. The high rate or penetration has in part stimulated Rwanda's economic activities, leading to the country's exceptional rapid economic growth over the past two decades. Despite this rapid economic growth, Rwanda remains in the least developed countries (LDCs) group with poverty rate of 38.2% and GDP per Capita of $772.97 (WB, 2021) and below the LDCs graduation threshold (UN, 2021). Like other least developed countries, Rwanda was hit hard by COVID-19 pandemic. As such, the recent report by the World Bank suggests that more than half a million additional people in Rwanda will be pushed under poverty line in 2021 (WB, 2021).

1 World Bank, Country Profile – Rwanda, https://databank.worldbank.org/views/reports/reportwidget.aspx?Report_Name=CountryProfile&Id=b450fd57&tbar=y&dd=y&inf=n&zm=n&country=RWA

2 MINICT and RBD (2017). Invest in Smart Rwanda

3 World Bank, Country Profile – Rwanda, https://databank.worldbank.org/views/reports/reportwidget.aspx?Report_Name=CountryProfile&Id=b450fd57&tbar=y&dd=y&inf=n&zm=n&country=RWA, accessed 7 July 2021

Box 1: ICT Capital Investment – Rwanda

Empirical research has indicated that higher level of ICT capital stock per capita allows a typical economy to achieve a higher output growth rate. Taking the data on ICT investments made by private and public enterprises in Rwanda is as a proxy for ICT capital investment. The average yearly ICT investment by the local and FDI between 2001-2015 was FRW 42.8 billion and the total investment was equivalent to FRW 641.8 billion. Using the average of the last five years, yearly ICT investment is estimated at FRW 87.2 billion, but it should be noted that capital flows (FDI) are mostly volatile and do not follow a smooth trend and linear trend. ICT investment projection is calculated based on the current trend, 5$ Billion value of opportunities for ICT projects and other ICT investment opportunities (SRMP's targets) and levels of ICT investments in other middle and high-income countries.

Source: MINICT (2017, p.46). ICT Sector Strategic Plan (2018-2024)[4]

2.1 Development Agenda: Rwanda

Rwanda's development agenda is encapsulated in various national frameworks and documents that outline key visions of the government, strategies, and policies. They include Vision 2050, the National Strategy for Transformation (NST1 2017-2024) and the STI policy. The Government of Rwanda's development agenda is underpinned by ambitious aspirations for the country to enjoy the living standards of upper middle income by 2035 and high-income countries by 2050 (GoR, 2020c, p. 50). Rwanda Vision 2050 goals are anchored in five pillars: i) Human development, ii) Competitiveness and integration, iii) Agriculture and wealth creation, iv) Urbanisation and agglomeration, and v) Accountable and capable state institutions (GoR, 2020c, p. 3). The Vision 2050 emphasizes the development of technological capabilities to attain the envisaged development goals, particularly in the areas of telemedicine, finance, and agriculture, all enabled by a capable 'data-driven economy'.

Capabilities and skills are central to technology development, appropriation, transfer, and management, as discussed in various sections of this report. Therefore, it is vital to address the capabilities and skills gaps in STI, as highlighted in this report and corroborated by NCST (2021) finding which revealed a 25% rate of innovation capacity at firm-level, in Rwanda. Furthermore, capabilities and skills, alongside the relevant policies and regulations, are essential for innovation and technology, which currently stands at rate of 11.1%, with technologies for processing, discussed in this report (see Section 5.3.4), in the lowest group (3.8%). This is lower than the percentage of institutions which implemented newly developed technologies (20.4%) (NCST, 2021, see pp. 27-28).

The NST1 aims to underpin Rwanda's development trajectory and the country transitions to Vision 2050. The NST1 objectives and priorities are summarised under four pillars namely: Economic transformation pillar; Social transformation pillar; Transformational governance pillar; and Cross-cutting areas. Under NST1, the Rwanda's public policy goal is to develop and transform Rwandans into 'capable and skilled people ready to compete in a global environment' (GoR, 2017a, p. 7). The aim is in part to enhance competitiveness by investing in capacity building and supporting technology acquisition, adoption, adaptation, upgrading, use and diffusion in key areas such as health, agriculture, infrastructure, education, environment, and ICT (GoR, 2017a, pp. 29–44).

Rwanda Vision 2050 and NST1 goals, objectives and priority areas and related interventions are aligned with regional and development agendas such as the African

4 Republic of Rwanda, Ministry of Information Technology and Communications (2017) ICT Sector Strategic Plan (2018-2024), Available at: https://www.minecofin.gov.rw/fileadmin/user_upload/Minecofin/Announcements/ICT.pdf, accessed 20 July 2021

Union (AU) Agenda 2063 and its first 10-Year implementation plan (2014-2023); East African Community (EAC) Vision 2050; United Nations (UN) Sustainable Development Goals (SDGs 2015-2030); and COP 21 Paris Agreement on Climate Change (GoR, 2020c, p. 6; GoR, 2017a, p. 14).

More specifically in the area of science, technology, and innovation (STI), Rwanda's 2020 STI policy focuses on five specific objectives: i) effective STI governance; ii) increased scientific and technology output; iii) increased Research and Development (R&D) and innovation financing; iv) improved STI capacity and knowledge networks development; and v) enhanced international STI collaboration (GoR, 2020b, p10). Enhanced international collaboration in STI is viewed as an important consideration for the country to realise the aspired goals and national development agendas. The summary of key science, technology, and innovation emphasis in Rwanda's Vision 2050, NST1 an STI policy is depicted in Annex 1. Table 1 below presents a summary of the key focus areas of Vision 2050, NST1, and STI Policy with implications on STI.

2.2 Political, Economic and Policy Environments

2.2.1 Political Environment

STI processes have an important place in Rwanda's politics. For example, digital technology (internet) is particularly regarded as 'a public utility as much as water and electricity, as declared by the president of the Republic of Rwanda (UNCTAD, 2017, p. xiii). Aside from political statements, Rwanda's commitment to science and technology (S&T) is generally reflected through the National Council for Science and Technology (NCST). NCST, attached to the office of the president, is the Rwandan government agency responsible for STI coordination, regulation and funding (Chataway et al., 2019). Technology occupies a place of pride in Rwanda, sitting right in the government top governance structure – the presidency. This strategic positioning of the NCST helps to demonstrate the importance that the Government of Rwanda (GoR) attaches to issues of STI. And the ways that politics in Rwanda affects, influences and shapes technologies (including science and innovation (S&I)) in the governance structure. A more detailed discussion on the main STI systems actors and stakeholders is presented in Section 3.

2.2.2 Economic Environment

Rwanda has recorded an exponential growth rate of the GDP in the last two decades, with around 11 per cent growth rate annually being registered for more than a decade. As such, the World Bank (WB)'s Doing Business surveys and the World Economic Forum (WEF) have been ranking Rwanda far higher than its relative development level. According to these metrics, the country's very high economic performance has been underpinned by, among others, three major factors namely: quality of institutions – including support and facilitations mechanisms to harness private sector; low levels of corruption; high levels of security and efficient labour market (UNCTAD, 2017, p. 4).

Building STI and entrepreneurial ecosystems takes a strong focus. In the quest to understand the extent to which Rwanda's developmental aspirations on STI are being translated into economic and entrepreneurial ecosystem, a study was recently undertaken on selected innovation hubs – viewed, conceptually, as foundation for 'knowledge economies', digital economies', or 'ecosystems'. Drawing on interviews with 47 stakeholders in technology entrepreneurship in Kigali (about 50% of whom are CEOs of nascent tech start-ups), that focused on two innovation hubs 'kLab' and 'The Office', the study revealed discrepancies between countries aspirational visions (national policies and strategies) and actual implementation realities of hubs. The challenges that underpin such discrepancies include "facets of community (such as boundaries and cultures) [that] need to be continually negotiated between hub leaders and entrepreneur, resulting in tensions and tradeoffs" (Friederici, 2018, p. 1). Such discrepancies, in part, undermines Rwanda aspiration to become the "Singapore of Africa" (p. 6).

Table 1: Summary of key focus of Vision 2050, NST1, and STI Policy

	Vision 2050	NST1	STI Policy
Goal(s)	To promote economic growth and prosperity, and high quality of life for Rwandans.	To develop Rwandans into a capable and skilled people with quality standards of living and stable and secure society.	To establish a vibrant STI environment with capacity, enabling policies, and adequate funding capable of producing quality graduates, research, and modern technology products and services to cater for the needs of the productive sector and the society
Pillars (Vision 2050) / Objectives (NST1, STIP)	• Human development • Competitiveness and Integration; • Agriculture and wealth creation; • Urbanisation and agglomeration; • Accountability and capable state institutions	• Move towards a poverty-free Rwanda; Ensure a quality health population; • Develop a competitive and capable Rwandan population; • Ensure quality of education for all aiming at building a knowledge-based economy; and Transition to a modern Rwandan household in urban and rural areas.	• Effective STI governance; • Increased scientific and technology output; Increased R&D and innovation financing; Improved STI capacity and knowledge networks development; and • Enhanced international STI collaboration.
Progress with implementation	• Creation of KIC; • Creation of continental and regional Centres of Excellence	• Creation of KIC; • Creation of continental and regional Centres of Excellence	• Creation and operationalization of the National Research and Innovation Fund (NRIF). NRIF. (NCST through NRIF is funding a number (91) of research projects); • Launch of National Research and Innovation Agenda and NRIF Policy Framework.
	Vision 2050	**NST1**	**STI Policy**
Treatment of technology	Development of new technologies and application/adaptation of existing advanced technologies	Promoting local production through 'made in Rwanda' policy and 'proof-of-concept' tech innovation approach.	UAVs, Satellite imagery; IoT in agriculture; Female technology; (Femtech) for inclusive health; Food technology (Foodtech); Online market; Fintech; Cyber-security; Data privacy and security; and Digital IDtech
Key focus areas	• Telemedicine; • Fin-tech; • Modern agri-tech; Artificial Intelligence (AI); • Internet of Things (IoT); • Robotics	• Fin-tech; • BPOs for service export; • MICE, • SMART classroom programme and deployment of ICT devices in schools	• Research on carbon-free energy, modern energy storage solutions, green transport, and smart grid solutions; • Research in modern techs (UAVs, Satellite imagery, IoT) and emerging techs in agriculture; • Research in augmented construction and mining industry; • Research in areas of tech-enabled creative industry solutions (such as online market), financial technology (Fintech), Cyber-security, Data privacy and security, advanced Digital Identification technologies (Digital IDtech); and • Big data driven research in clean tech and green production processes, Biodiversity Conservation, Tech-enabled atmospheric and climate science

Sources: Author's compilation, with insights from: GoR (2017a); GoR (2020b); GoR (2020c); Yongabo and Göktep-e-Hultén (2021)

2.2.3 Policy Environment

The Rwanda policy environment is broadly characterised by a 'decentralised' policymaking process[5]. This is informed by the national decentralisation policy that was adopted by the Government of Rwanda in 2000 (Rusuhuzwa Kigabo, 2008). The aim of that paradigm shift was threefold: (i) achieving good governance, (ii) ensuring pro-poor service delivery; and (iii) achieving sustainable socio-economic development (Rusuhuzwa Kigabo, 2008, p. 18). The decentralisation policy was hereto [and still is] implemented by the local authorities (districts) and coordinated by the ministry in charge of local government.

Contrary to the decentralised policymaking process, but related to some extent, national and sector-specific policies – including the STI Policies – are formulated by respective line ministries and submitted to Cabinet for approval. The implementation of these policies is undertaken by central government institutions (or agencies) affiliated to respective ministries. The overall coordination and monitoring of government policies (from both central and local government institutions) is mandated to the office of the prime minister, which in term reports to the office of the president of the Republic of Rwanda[6]. Understanding the workings of the policy environment and the policy processes has implication on the implementation of the recommendations of this report (see Section 6).

2.2.4 Covid-19 pandemic era

Covid-19 pandemic has impacted the Rwandan ecosystem, like every other country across the globe, resulting in changes that are relevant to this technology analysis. Questions worth exploring include: How has the political, economic and policy environments changed because of Covid-19? And what are the implications of such changes on science, technology, and innovation? Guided by international science, Rwanda was among the first countries in Africa to implement rapid and stringent measures aimed at curbing the spread of Covid-19 pandemic. Right after only one positive case was identified on 8th March 2020, countrywide total lockdown was enforced on 21st March, 2020[7]. This was followed by the directive of making it compulsory for everyone to constantly wear face masks in addition to maintaining one meter of social distancing. Rwanda's timely and robust response was less surprising as it followed similar stringent preventive measures against Ebola outbreak in 2019 (Edwards, 2020).

Technology has particularly underpinned Rwanda's national policies and strategies in response to Covid-19 pandemic. Examples include: i) dissemination of public information and awareness through Unmanned aerial vehicles (UAV) a.k.a drones, ii) use of 'smart anti-epidemic robots' for screening and patient care through effective and efficient patient treatment using advanced digital solutions, and iii) official communication through social media platforms revealing existing digital technology infrastructure (Karim et al., 2021). This was in addition to rapid transition from physical to online teaching and learning during and after closure of educational organisations, which was underpinned by the existing digital infrastructure and agile ICT policies and strategies. Part of rapid response to Covid-19 pandemic also included the issuance of a special call made by the Rwanda's science granting council (SGC) to support collaborative research to address the pandemic[8].

Despite the robust political measures, related policy changes, and response by the population, Covid-19 pandemic has and continues to affect Rwanda adversely – both in the social and economic aspects. The severe impacts to major sectors of national economy: trade, small and medium-sized enterprises (SMEs) are well documented (Bizoza and Sibomana, 2020). According to WB, Rwanda's GDP growth was expected to increase by 8% before Covid-19 outbreak, but this is estimated to have plunged by 0.2% in 2020, pushing the country into its first economic recess since 1994 (WB, 2021, p. 4). Relatedly, Rwanda' public debts

5 Defined by Rusuhuzwa Kigabo (2008), policymaking process refers to a procedure by which policies are discussed, approved, and implemented. This process is intended to be dynamic and interactive and involve all stakeholders.

6 Office of the Prime Minister, Republic of Rwanda

7 Office of the Prime Minister, Republic of Rwanda: *Announcement on Enhanced Covid-19 Prevention Measures*

8 Rwanda National Council for Science and Technology (NCST)

have increased from 58.1% of GDP in 2019 to 66% in 2020, while unemployment rate has surged from 13 to 22 % during the period of total lock down 9 (from March to May 2020).

Rwanda's quick recovery through strategic growth sector (MICE) is unlikely due to prevailing travel restrictions as well as the anticipated travel 'fear factor' in post Covid-19 era. In contrast, agriculture sector was less hit by the pandemic when compared to services and manufacturing sectors, although the former was adversely affected by weather conditions – heavy rains and floods – leading to decrease in food production and crop exports (WB, 2021, p. 6). Robust policy intervention will be needed for Rwanda's long-term recovery, resilience, and growth after the pandemic. Technology and innovation have a key role to play in the recovery. In addition, emphasis should be put on health and education systems, and human capital broadly (WB, 2021, pp. iv–v, 6), and economic recovery particularly in SMEs (Bizoza and Sibomana, 2020).

Economic Recovery Fund (ERF) in response to Covid-19 pandemic:

The Economic Recovery Fund (ERF) worth 101 billion Rwandan Francs was created in 2020 by the Government of Rwanda (GoR) as part of revised medium term macro-economic framework in response to Covid-19 pandemic (GoR, 2020d). Managed by the National Bank of Rwanda (BNR), ERF's aim was twofold: (i) Supporting businesses in sectors, mostly affected by the pandemic, to survive, resume work and (or) production, and safeguard employment; and (ii) Expanding domestic production of essential products during Covid-19 pandemic and in post-Covid-19 era. The products include medical equipment such as face masks, glove, sanitisers, and disinfectants. In this sense we see the role of technology and innovation in helping to address the impacts from Covid-19. Eligible sectors to benefit from ERF include tourism, manufacturing (including Agri-processing), transport and logistics and small and medium-sized enterprises (SMEs) making part of local and global supply chain. Fig 2[9] illustrates the total Fund (101 Bn Frw) allocation in % age per sector as at end May-2020[10].

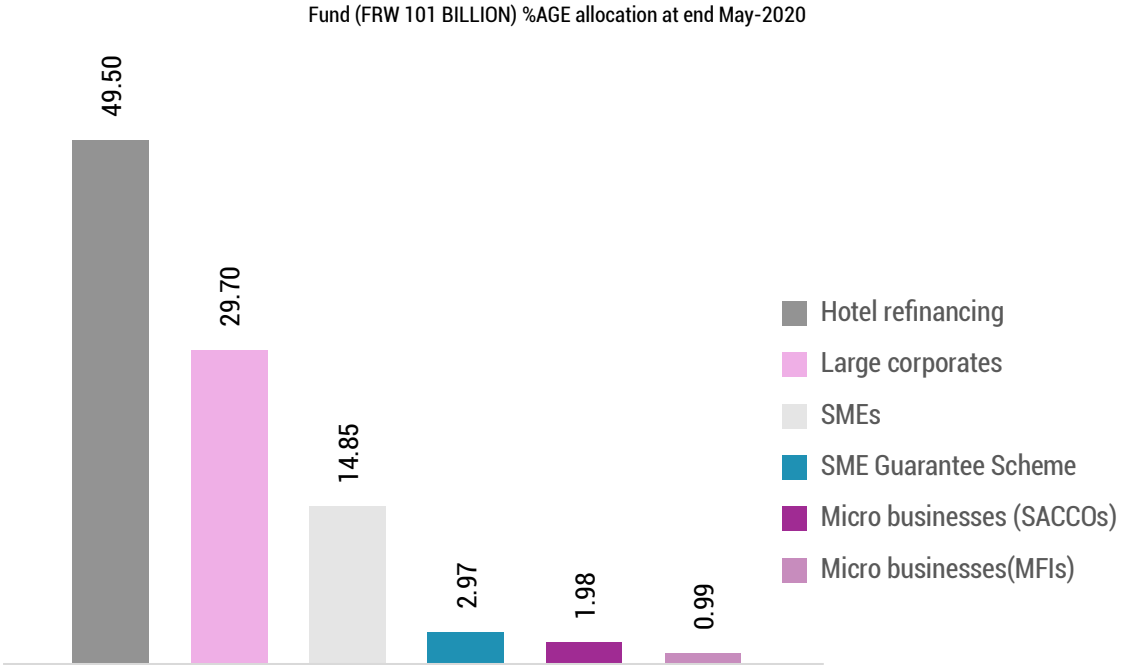


Figure 2. ERF allocation in % age per sector as at end May-2020. *Source: Author' compilation, adapted from GoR (2020d)*

9 According to BNR; Large corporate is a business with annual turnover above RWF 500 million (M); SME is a business with annual turnover ranging between FRW 20M and 500M; and Micro business is a business with annual turnover less than RWF 20M. Informal microbusinesses were eligible to access ERF through Micro business (MFIs) window subject to demonstrating proof of local tax payment.

10 Republic of Rwanda, National Bank of Rwanda (2020) Economic Recovery Fund, Available at: https://www.bnr.rw/fileadmin/user_upload/ERF/Allocation_of_funds.pdf

2.3 Priority Areas and Sectors and Development Agenda

The STI policy of Rwanda aims for the country to attain and sustain 'an innovation–driven society through efficient and effective application of knowledge and technology'. The goal of STI policy, mission and objectives is for Rwanda to transition from a nascent to functional innovation system. Aligned to the pillars of NST1 and Rwanda Vision 2050, and given the scarcity of human and financial recourses, the STI policy adopted in 2020, propose the following six priority sectors:

1. Sustainable energy;
2. Food security and modern agriculture;
3. Health and life sciences;
4. Local production and value addition;
5. Digital services, products and lifestyle; and
6. Environment, tourism, natural resources and climate change (GoR, 2020b, p. 23).

It is believed that implementation of NST1 and Vision 2050 goals through these STI priority sectors, will enable Rwanda to become a knowledge-based economy, and achieve the aspiration of moving to an Upper Middle-income Economy by 2035 and High-income Economy by 2050. STI is central to realising these ambitions. Drawing on aforementioned priority areas and the related sectors outlined in the Rwanda's STI policy and considering the related pillars of NST1 and Vision 2050, we consider the following priority sectors highlighted below for the purpose of this study. We extend the priorities and introduce a few areas of importance under the broad heading of "cross-cutting sectors".

1. [Sustainable] Energy
2. [Food Security and Modern] Agriculture
3. [Life and] Health [Sciences]
4. [Local Production and Value Addition] Manufacturing
5. ICT and Innovation [Digital Services, Products and Lifestyles]
6. [Resilience,] Environment [and Climate Change]
7. Cross-cutting [sectors]: Gender; Education; Finance and Services; and Infrastructure.

To help deepen the understanding of the context and the role that technologies could play in realising Rwanda's development agenda, as discussed above, we examine the identified areas of priorities, needs and sectors. As noted in Chapter 1, the TNA focuses on two sectors: Agriculture and Manufacturing. These sectors were jointly agreed with key STI actors and stakeholders at the workshop held on 8 July 2021, hosted by the MINICT. Although the TNA focuses on agriculture and manufacturing, and the technologies in these sectors; the other sectors – Energy, Health, ICT and Innovation and Environment – alongside the cross-cutting areas outline above, will be treated as thematic areas that cuts across the two TNA priority sectors. The six sectors are discussed below to help provide overview. Thereafter, the TNA (Sections 4-6) focuses on the two priority sectors for the TNA.

Energy

Rwanda's Vision 2050 suggests that 'there will be continued emphasis on clean and renewable energy as a source of generation with at least 60% of installed capacity from 53.7% in 2020. (GoR, 2020c, p.33). The Rwanda's energy policy (2015) and the related Energy sector strategic plan (2018/19-2023/24) propose approaches for attaining the goals of Rwanda's Vision 2050 through three energy subsectors namely: electricity, biomass, and petroleum[11]. New technologies are required in the development and distribution of energy (carbon and renewable) to meet the demands in both urban and rural areas (UNCTAD, 2017). Relatedly, the development of local capacities to install, run and maintain these technologies is key, hence interactions between government, industry, and education (including TVET) is paramount (UNCTAD, 2017, p. 50).

A recent analytical study on barriers to biogas dissemination in Rwanda reveals that biogas technology was introduced as alternative energy solution in rural areas of Rwanda. The government target for installing 15,000 biogas plants by 2012 was never met. The study identifies four main factors that have undermined the dissemination and adoption of biogas technology

11 Rwanda Energy Policy (2015) and Energy Sector Strategic Plan (2018/19-2023/24) https://www.mininfra.gov.rw/publications [Accessed: 19.07.2021]

namely: financial constraints, technical capacity, and socio-cultural and institutional challenges, with finance ranking the most influential hindrance. Policy recommendations for accelerating biogas uptake in rural areas are proposed (Mukeshimana et al., 2021). Another study on demand for off-grid solar electricity in Rwanda suggests that off-grid solar energy system is the most preferable technology to attain mass electrification in most rural regions of Africa, with grid infrastructure being recommended for region with relatively high economic status.

Rwanda's development visions and strategies put strong emphasis on renewable energy, but no specific targets for photovoltaic (PV) technologies (Nygaard et al., 2017). Despite the challenges and inability of citizens to cover the price of the technology, households across Rwanda are keen to embark on off-grid solar systems (Grimm et al., 2020). Policy instruments with clear targets are paramount for photovoltaic technologies in rural and urban areas alike. Viewed through the urban development lenses, a comparative study of economic power generation models in Kigali suggests that that grid-connected photovoltaic (PV) and battery micro-grid model are relatively low-cost, reliable and affordable model of power generation technology for residential households in Kigali (Nsengimana et al., 2020).

Agriculture

The use of digital and modern technologies in agriculture is one of the five (5) pillars of Rwanda's Vision 2050 (GoR, 2020c). A recent study on emergence of agriculture innovation system suggests that agriculture is a dominant socio-economic sector with high innovation potential. This is captured by the National Agricultural Policy (2018) and Industrial Policy (2011), which explicitly propose the promotion of agricultural (agri-) technologies such as: land-saving technologies, technologies suitable for agro-climate zones for crops, post-harvest and integrated pest management technologies, latest high-resolution GIS technologies, bio-fertilizer technologies, irrigation technologies, mechanisation technologies, and labour-saving technologies among others[12].

Specialised research and technology transfer programmes (including community-based technology transfer tools), and market diversification are emphasised as key policy initiatives in the sectoral and local agricultural strategies. However, there is the need for capacity building, stakeholder engagement, and needs assessment to underpin the selection, adoption, application and use of new technologies (Yongabo and Göktepe-Hultén, 2021). Emphasis needs to be placed on 'support technology adoption for specific farm types and the involvement of a wide range of actors and stakeholders – including farmers, across different parts of Rwanda. This data-driven tailored approach contrasts with the prevailing 'on-size-fits-all' model of agricultural technology adoption (Hammond et al., 2020).

An examination of the technology and innovation trajectories in the agriculture sector proposes the 'Value chain structural organisation' as option for technology and innovation mainstreaming in Rwanda's agriculture sector. The study also reveals that limited 'technological absorptive capacity' and 'mismatch in interest' among actors are part of the key factors the hinder interactions, and knowledge and technology transfer. One recommendation is to create synergies among programmes, projects and policies to help foster 'interactive learning' amongst actors (Yongabo, 2021b). Synergies in this regard can promote co-creation, diffusion and use of both normative (scientific) and tacit (indigenous) knowledge, and hence optimise the 'potential of value chains in integrating technology and innovation in the agricultural sector'. The effective deployment of 'digital and other technologies for agricultural development and commercialisation can serve the purpose in this regard (UNCTAD, 2017, p. 24). Moreover, developing biodegradable packaging technologies for agriculture and Agro-food sectors, industry and trade services and logistics, would not only help Rwanda to achieve its long-term development agenda but it would also position Rwanda as a regional leader in these domains (UNCTAD, 2017).

12 Rwanda Agriculture Policy (2018) https://www.minagri.gov.rw/fileadmin/user_upload/Minagri/Publications/Policies_and_strategies/National_Agriculture_Policy_-_2018___Approved_by_Cabinet.pdf [Accessed:19.07.2021]

Health

The scientific and technological advances in health sectors are key part of drivers of the development trajectory to bring Rwandans to envisaged high quality health and lifestyle by 2050. Whether Rwanda will meet this ambitious target is contingent up on how the country will invest in human capacity development, research and educational infrastructure, and relevant technologies. There are indications of a shortage of skilled medical and health manpower in the area of new technologies such as imaging technologies (UNCTAD, 2017, p. 35). A study assessing a large-scale national distribution of phototherapy (PT) for children severely affected by hyperbilirubinemia across hospitals in Rwanda reveals that technological infrastructure need to be complemented with diagnosis capacity for optimal impact healthcare (Sheth et al., 2021).

Nonetheless, the use of emerging technologies such as UAVs[13] commonly referred to as 'drones', in public health service delivery, demonstrates Rwanda's policy agility and readiness to embrace new technologies for public purpose. In Rwanda, UAV technology has successfully disrupted public health logistics including expanded delivery services such as blood transportation, and improved vaccine coverage. For instance, UAVs were particularly instrumental in fastpacking the distribution and administration of vaccine for coronavirus in Rwanda (Karim et al., 2021). In addition, drones are generally utilised in public health care systems for transport logistics in remote areas and in public health surveillance at a relative low cost (Bhattacharya et al., 2020). Aside from positive gains brought into healthcare system by UAVs, the use of this technology in public health care presents numerous shortfalls such as 'technical difficulties in operating UAVs, maintenance of UAV device and systems, regulatory challenges, safety concerns, air traffic congestion, and cost of using UAVs' (Bhattacharya et al., 2020). Table 2 below helps to illustrate some of the technical challenges of UAVs deployment in public health and proposed remedies.

Drawing on Table 2, robust strategies, policy interventions and absorptive capacity are required for UAV technology transfer and acquisition in its fullness. Intentional investment in R&D is equally paramount for knowledge production, entrenchment, and sustainability of the technology within the broad national R&I and economic system. The existing knowledge infrastructure such as University of Rwanda (UR) Centre of Excellence (CoE) in IoT and AIMs-Rwanda would collectively play a crucial role in advancing knowledge and technological capability in UAV technology not only for health sector but also for other domains of national development such as agriculture, mapping and planning, and construction. Moreover, structural settings – including regulatory framework- and capacity conditions constitute key factors hindering the potential of unmanned aerial systems (UAS) as special data technology for Rwanda's development needs in the areas of land administration and spatial planning (Stöcker et al., 2019).

Table 2: Drone use in public health service, challenges, and proposed solutions

	UAVs Technical issues/requirements	Proposed solutions
Operation and maintenance	Drones require trained personnel and constant monitoring from the ground	Gradual training
Technical issues	UAV are battery powered	Solar–powered UAV
	Outdoor UAVs are supported by GPS signal and radio frequencies to fly and accomplish their duties, but the reception of the signal is less than optional in indoors	Use of Wi-Fi technology
	Present UAVs are not fully intelligent i.e., not fully automated in such a way that they can be cognisant of the environment	Embedding new technologies such as artificial intelligence (AI)

Source: Author's compilation, based on Bhattacharya et al.(2020)

13 A.k.a uncrewed aerial vehicles, or unmanned aircrafts, or unscrewed aircrafts

Manufacturing

Rwanda's NST1 places special emphasis on technology in manufacturing as way of transforming the industrial sector, and hence attain 'high-value goods and services' export. This is partly attained through private sector-led 'Made in Rwanda' policy (2017), with the overarching goal to foster the Rwanda's domestic market through 'value-chain development'[14]. Made in Rwanda policy targets the creation and expansion of specific manufacturing industries by 2024. Target areas include pharmaceutical plants, manufacturing plant for mosquito nets, chemical fertilizer plants, and industries for production of construction materials such as ceramics, steel and iron, and cement, and packaging materials plant (GoR, 2017a, p. 20,29).

In response to Rwanda Law no: 57/2008 banning the use of plastic bags, Made in Rwanda policy places emphasis on packaging technologies particularly for Agro-processing industry. Therefore, the policy proposes the creation of a Centre of Excellence (CoE) in packaging aimed at supporting SMEs in packaging and branding. The implementation of Made in Rwanda policy in general, and the operations of the CoE are to be overseen by the Rwanda's National Industrial Research and Development Agency (NIRDA). NIRDA, the implementing arm of the Ministry of Trade and Industry (MINICOM), is responsible for supporting private firms (SMEs) and industries through R&D and technologies to boost the private sector competitiveness. Made in Rwanda policy is complemented by law no: 005/2021 promoting and facilitating investment, by both local and international firms. The enforcement of the law is overseen by Rwanda Development Board (RDB)[15].

Additionally, to NST1, the Rwanda's STI policy recognises the need of combination and complementarity of imported technologies with indigenous (local and traditional) knowledge and expertise in effort to tech adaption as part of 'Made in Rwanda' strategy (GoR, 2020b, p. 14). And the promotion of indigenous knowledge, home grown solutions and local technologies is given particular emphasis (GoR, 2020b, p. 16). A recent study on the political economy of SCGs in SSA, calls on Rwanda to leverage strong focus on TVET education to revitalise and expand private sector through creating innovation-driven businesses in addition to the 'formal manufacturing of products' (Daniels, 2020, p. 28). However, it is essential to unpack and re-categorise what constitutes 'private sector' in Rwanda's unique context, as obtained in the rest of SSA (Daniels, 2020).

ICT and Innovation

Rwanda aspires to position the country as a leader in STI, with particular emphasis on ICTs. With respect to digital infrastructure, Rwanda has launched ambitious plans for the high-tech sectors and created Centres of Excellence in advanced technologies in past few years (UNCTAD, 2017, pp. 13–14). For instance, the Kigali Innovation City (KIC) project, was launched in 2016 as flagship programme to accelerate Rwanda's transformation towards knowledge-based economy. KIC's initial focus was on digital technologies as enablers for innovations in other sectors (UNCTAD, 2017, p. 25, 37). Part of its knowledge platform, KIC hosts the global and regional leading educational and research organisations including, inter alia, the Carnegie Melon University in Africa (CMU-Africa) – a regional CoE in ICT with the aim to build and strengthen capabilities and skills in digital, at comparative global scale. Promoting technological and innovation capabilities development, with particular emphasis on the youth, remains part of the priorities for incumbent Ministry of ICT and Innovation (MINICT) in Rwanda.

A recent development in Rwanda's digital tech ecosystem is the creation of Technology Support Centre (TSC) in Kigali, Rwanda by T.E.K Experts, with the Centre's operations envisaged to begin in July 2021 as approved by Cabinet of GoR on 18th January, 2021. According to Paula Ingabire, Rwanda's Minister of ICT, and Innovation, TSC will mark a paradigm shift in the 'Rwanda's technology landscape' particularly with regard to current challenge of 'under-utilised talents'. Training

14 Made in Rwanda Policy 2017 https://www.nirda.gov.rw/uploads/tx_dce/03_05.pdf [Accessed:19.07.2021]

15 Republic of Rwanda (2021) Year 60 Official Gazette, Available at: https://rdb.rw/wp-content/uploads/2021/04/new-investment-law-2021.pdf

will be a major component of the project that will seek to employ 1,000 staff with only 40% of employees being foreign talents. It is anticipated that, MINICT will be collaborating with universities in Rwanda 'to get a good pipeline of eligibility to improve the skills and expertise of young Rwandans within the [ICT] sector'. T.E.K Ltd is a UK-based company specialising in electrical, mechanical and software development solutions[16].

At the visit to Rwanda's youth tech hubs in Kigali, named KLab and FabLab by Mr. Hafez Ghanem, the World Bank Vice President for African Region, the Rwanda Minister of ICT, and Innovation mentioned that Rwanda was planning to devise 'policies that enable start-ups to compete at same level with large bidders'. The Minister also stated that 'to allow Rwanda to become an innovation hub, the Government is open to free flow of labour and opening up Rwanda as a Proof-of-Concept hub' (GoR, 2019c). In similar vein, Rwanda Coding Academy (RCA)[17] was established by GoR in 2019 as a 'proof-of-concept' model school to provide secondary education level students with ICT and other 21st century (soft skills). According to MINICT, RCA specialises in teaching and training in software development, embedded systems programming and cyber security to smart students who are 'born to code' (GoR, 2021).

Despite the government efforts in building a robust digital talent base, access to digital technologies remains a policy issue deserving due attention if Rwanda is to become a tech-driven innovation hub. For instance, a recent study on special analysis of urban digital divide[18] in Kigali reveals a correlation between incumbent urban inequalities in infrastructure, urban agglomerative strengthen, planning status and household socio-economic status on the one hand, and digital divide[19] on the other hand, in the city of Kigali. This calls for ICT policy interventions targeting urban inequalities in Kigali, the Rwanda's capital city and innovation hub (Otioma et al., 2019).

Environment

Environment is considered as part of key and priority sectors for Rwanda to achieve sustainable development. As stated in NST1, promoting sustainable management of the environment and natural resources to transform Rwanda is therefore viewed as priority area to help drive Rwanda towards a Green Economy (GoR, 2017a, p. 67). One action in this respect is the creation of a specialised fund named Rwanda Green Fund (FONERWA). FONERWA operates under the auspices of the Ministry of Environment (MoE), with funding from GoR and collaborative development partners including FCDO (formerly DfID) and KFW, as well as international organisations such as UNDP. FONERWA aims to provide 'unheralded technical and financial support to the best public and private projects that align with Rwanda's commitment to a green economy'[20]. FONERWA is also viewed as a facilitation mechanism to potentially foster research and innovation (R&I) actor interactions and thus enhance Rwanda's NSI performance, including developing technological absorptive capacity and capabilities (Twiringiyimana et al., 2021). Strengthening R&I actors' interactions in the areas of environment, climate change and disaster management are vital to achieving Rwanda's development agenda. Technology will continue to play a critical role in this respect.

In summary, although six (6) priority sectors have been discussed in this report, in line with the STI Policy of the Government of Rwanda (GoR, 2020b), the Technology Needs Assessment (TNA) will focus on two sectors. As indicated in Chapter 1, these sectors of focus were determined in consultation with the STI stakeholders through focused group discussions (FGDs) involving key experts from the six sectors briefly discussed above.

16 https://ket.ltd.uk/about/ [Accessed: 20.04.2021]

17 Republic of Rwanda, Ministry of ICT & Innovation (2019) Rwanda Launches The First Coding Academy, Available at: https://www.minict.gov.rw/news-detail/rwanda-launches-the-first-coding-academy [Accessed:20.04.2021]

18 It is important to consider the rural urban divide, and differences between cities. Currently, majority of organisations and departments are based in Kigali.

19 Digital divide: defined by Otioma et al. (2019) as uneven access to information and communications technologies (ICTs) and its potentials for cities (or countries or else regions), across geographies and demographics.

20 http://www.fonerwa.org/ [Accessed: 05.06.2021]

Table 3: Proportion of women in selected areas

Proportion of women in parliament (chamber of deputies)	61.3%
Proportion of women in cabinet of ministers	50%
Proportion of girls' enrolment in primary school level (2018)	49.7%
Proportion of girls' enrolment in general secondary school level (2018)	53.2%
Proportion of women enrolment in TVET programmes (2019)	41.7%*
Proportion of female students in higher education (2018/19)	43.1%*
Proportion of women enrolment in STEM programmes in higher education (2018/19)	32.1%*
Proportion of female students in TVET higher education (2018/19)	28%*

Sources: Author's compilation, based 2019 Rwanda VNR GoR (2019b); Rwanda 2019 Education Statistics (GoR, 2019a)*

The FGDs was complemented by a virtual workshop held on the of 8th July 2021, via Webex. The workshop brought together policy-makers and experts from the aforementioned priority sectors of Rwanda's national development. Drawing on the recommendations from this stakeholder workshop, the TNA focus on take priority sectors: Agriculture and Manufacturing. Although the TNA focuses on Agriculture and Manufacturing, cross-cutting areas that are vital to Rwanda's development will be captured in the TNA. The cross-cutting areas are briefly examined below to help provide context.

Cross-cutting areas

Although ICT is considered to be part of the priority sectors, it is equally viewed as a cross-cutting area in a sense of it being an enabler for the achievement of the goals and objective of the aforementioned priority sectors (Dosso, 2020). In addition to ICT and for the purpose of this study, other key crosscutting areas include gender, education (in the broad sense of capacity building) and finance. For instance, the Girls' Education Policy (2008)[21] aimed at addressing the issues of disparities in education has been jointly overseen by the Ministries of Gender and Family Promotion (MIGEPROF) and Education (MINEDUC). In a similar vein, the Workplace learning policy (2015)[22], aimed at preparing the Rwandan youth for employment, is jointly overseen by the Ministry of Public Service and Labour (MIFOTRA) and MINEDUC. Particularly, the Higher Education Policy (2008) and TVET policy (2015) are overseen by MINEDUC[23].

The Ministry of Finance and Economic Planning (MINECOFIN) oversees the budget allocation for implementation of programs and projects under the aforementioned priority sectors. Research and innovation (R&I) programmes in the priority sectors discussed above are stipulated in the national R&I agenda, and are funded through the National Research and Innovation Fund (NRIF), a consolidated fund which is managed by the National Council for Science and Technology (NCST) (Twiringiyimana et al., 2021).

2.4 Technology Needs Assessment Projects and Related STI Initiatives

The Rwanda STI review and TNA draws on and adds to the work already undertaken on Rwanda STI system in recent years. Some the relevant work and initiatives are discussed briefly below.

1. UNESCO Global Observatory of Science, Technology, and Innovation Policy Instruments (GO-SPIN): a study of 'Mapping research and innovation in the Republic of Rwanda' was conducted in 2015. The study identified Science, Engineering, Technology, and Innovation (SETI) key operational policy instruments aimed to facilitating research

21 Girls' education policy (2008) https://www.migeprof.gov.rw/publications/policies-strategic-documents

22 Workplace Learning Policy (2015) https://www.mifotra.gov.rw/publications

23 Higher education policy and TVET policy https://www.mineduc.gov.rw/publications [Accessed:23.07.2021]

and innovation (R&I). Among other findings, the study highlighted the gaps in the implementation of the policy instruments and implications on the performance of Rwanda's STI system (Lemarchand, 2015; GoR, 2020b).

2. Rwanda STI Policy Review: a review of Rwanda's STI policy was conducted in 2017 by UNCTAD. The review focused on the national STI policy of 2005. The aim of the review was threefold: (i) Assessment of the framework conditions and interactions required for a functioning NSI; (ii) Studying key challenges for fostering NSI based on reviewing four sectors: energy, Information and Communication Technologies (ICTs), agriculture, and industry; and (iii) Providing recommendations for strengthening policies and proposing mechanisms to improve Rwanda's national technological capabilities. The review highlighted major gaps including the lack of policy implementation strategy, inadequate interactions among actors, lack of synergies for collaboration between government, industry and academia, particularly in ICT sector, as well as weaknesses in financial resources, making Rwanda's NSI 'embryonic' (UNCTAD, 2017; GoR, 2020b). These challenges are also highlighted in recent scholarly research on STI systems in Rwanda and in Sub-Saharan Africa (SSA) region (Yongabo and Göransson, 2020; Twiringiyimana et al., 2021). A recommendation from the UNCTAD review is the emphasis on Rwanda's new STI policy to be formulated based on NSI conceptual framework, in part to allow effective monitoring and evaluation (M&E) of its implementation. The Rwanda's new STI policy, approved in June 2020, was thus formulated in part based on this recommendation (GoR, 2020b).
3. Technology Ecosystem Outlook – Rwanda: The outlook was produced and published by BriterBridges (2019), with the following major findings regarding Technology (Tech) Ecosystem Outlook in Rwanda as at Q1 2019:

- There were nine (9) Tech main support hubs in Rwanda:
  - kLab,
  - FabLab Rwanda,
  - Impach Hub Kigali,
  - Startup Grind,
  - WSH,
  - Inkomoko,
  - CcHUB Design Lab,
  - HuzaX, and
  - IRIS Hub
- Rwanda co-organised and hosted major global events in 2019 including:
  - Youth Connekt,
  - Smart Africa, and
  - Mobile 360 Africa (GSMA)

The organisations outlined above are examples of actors from tech ecosystem only. The broader NSI mapping with actors from government, industry, academia, and non-governmental organisations is discussed in greater depth and presented in Section 3.

2.5 Rwanda's Commitments to the SDGs

Drawing on the 2019 Rwanda Voluntary National Review (VNR) Report, Rwanda's commitment to SDGs can be viewed into two perspectives. On the one hand, Rwanda played a prominent role in designing the process and in supporting with delivery process of the Goals on a global and regional scale. This is respectively justified by: (i) Rwanda was selected as a pilot country for SDG 16 on building effective and capable institution, and (ii) Rwanda hosting the SDG Centre for Africa (SDGC/A) mandated to support African countries in the integration and implementation of the SDGs (GoR, 2020b, p. 9). On the other hand, Rwanda has put in place mechanisms to domesticate and own the SDGS, and thus facilitate fast implementation of the same through the mainstream national development agenda. For instance, Rwanda adopted its Green Growth and Climate Resilience national strategy for climate change and low carbon development in 2021. This strategy marked Rwanda's 'initial steps on pathway which leads to a sustainable

and secure future'[24]. Besides, under coordination of the ministry of finance and economic planning (MINECOFIN), Rwanda has strategically aligned the NST1 (2017-2024) three pillars: economic transformation, social transformation, and transformative governance (see details in Fig 2), to the three SDGs dimensions: economic, social, and environmental.

This integration of SDGs dimensions into NST1 priority sectors, has in part facilitated the addition of key goals and related targets into the policies, strategies, planning, budgeting, and implementation of the SDGs at various levels and sectors of Rwanda's governance structures (GoR, 2019b, pp. 14–15). Although all the 17 SDGs were considered relevant on equal footing in Rwanda's development agenda, particular attention was paid on specific areas such as gender (to eliminate gender inequalities and disparities), and sustainable agriculture (taking into consideration the environment and climate change). For instance, the Rwanda's constitution 'confers at least 30% of positions to women in all decision-making organs', hence Rwanda is one of the leading countries globally with a higher number of women in parliament (61.3%) (GoR, 2019b, p. 19). Table 3 provides a summary of other examples of Rwanda's progress regarding the SDGs and related goals. Table 4 provide specific examples of STI investment progress in relation to SDG9.

Concerning the environment, the Rwanda Green Growth fund (FONERWA) (discussed in section 2.2 above), was created in 2012 with the aim to support innovations for Rwanda sustainable economic development. Part of FONERWA's main achievements include: 19,642 hectares of land protected against soil erosion; 137,785 green jobs created; and 61,592 households provided with improved accessed to off-grid clean energy (see GoR, 2019b, p. 43 for more on this). Despite efforts put in place by Rwanda, financial and human capacity deficits remain part of the key challenges in the implementation of the SDGs, (GoR, 2019b, p. 17). Technology can be a major contribution to overcoming these challenges. As discussed below, there are concerted efforts in Rwanda to pilot the STI potential to enable and accelerate the implementation of SDGs, particularly for territorial and industrial development.

STI for SDGs Roadmaps

Drawing on the report of first the workshop on STI Roadmaps for SDGs organised by the European Commission Joint Research Centre (JRC), in collaboration with Rwanda MINICT held in January 2020, it was recognised that, in the context of 'Smart Specialisation in innovative and informal economies', smart specialisation strategy (S3) can contribute to Rwanda ability 'to achieve sustainable territorial [place-based] and industrial development' … living no one and no place behind (Dosso, 2020, pp. 3, 12). The perceived/anticipated challenges for implementation of smart specialisation in Rwanda include the 'formulation of challenges and innovation priority domains within multi-stakeholders' participatory settings, and commitment and coordination of stakeholders beyond the two helixes of government-industry or university-government (Dosso, 2020, p. 9).

Incubation, local technology promotion and commercialisation/diffusion, and Skill-building for market analysis and technology watch to support appropriate technologies, were identified amongst key activities to be undertaken under Smart Specialisation framework to help address the development challenges related to the Rwanda's key priority sectors (Dosso, 2020, p. 10). In addition to local technologies, non-technological innovation solutions – such as home-grown solutions stemming from a combination of 'indigenous and external knowledge'- are also regarded as potential to achieving SDGs (Dosso, 2020, p. 12). Despite long-term vision and political aspirations, the report revealed that innovation (and indeed technology) development in Rwanda is undermined by four major factors namely: (i) lack of appropriate infrastructure and funding, (ii) critical mass of skilled human capital, (iii) market access, and (iv) diffusion of knowledge (Dosso, 2020, p. 12).

24 UNDES, The Partnership Platform, Available at: https://sdgs.un.org/partnerships [Accessed: 23.07.2021]

Table 4 below illustrates some examples of Rwanda's progress in STI in relation to SDG9: industry, innovation, and infrastructure. This report contributes to achieving the 17 SDGs, but especially SDG 9, and 1-8, and 10.

To summarise the discussions, the materials presented in this section and the corresponding analyses have attempted to unpack the Rwanda's development agenda with a focus on the political, economic, and environmental considerations. The discussions highlight existing gaps and opportunities in relation to how technology underpins Rwanda's aspired social and economic development, through the six priority sectors:

Energy, Agriculture, Health, Manufacturing, ICT and Innovation, and Environment, as stipulated in Vision 2050 and NST1(2017-2024). The insights demonstrate the importance of existing challenges and gaps to be addressed for STI to foster the implementation of SDGs through emerging initiatives such as S3. The following section presents the Rwanda STI system and policy framework. The discussions that follow in Section 3 help to show how greater interaction, collaborations, better governance of the STI systems and the application of technology can help to a) resolve the identified challenges and b) ensure that Rwanda harnesses the opportunities from STI.

Table 4: Rwanda's progress on STI related SDG 9 – Industry, Innovation, and Infrastructure

SDG 9	Current Progress
Building resilient infrastructure	• Improved investment in energy, transport and logistics, and services. • Rwanda is investing in railway infrastructure, with Tanzania and Burundi.
	• Build strong ICT infrastructure through fiber optic network • 96.6% of population covered for 4G mobile cellular network in 2018/9
	• Heavy investment in air transport infrastructure services. For example, RwandAir passenger number increased from 377,327 in 2012 to 926,571 in 2017/8. And Kigali International Airport and Kamembe Airport upgraded
Promoting sustainable industrialisation	• Developing Special Economic Zones (SEZs) and Industrial Parks e.g., Kigali SEZ adjacent to KIC
	• Made in Rwanda Policy (2017)
	• Manufacturing value added as proportion of GDP: 6% in 2018. • Industrial sector contribution to DGP was 17.0% in 2018
	• Manufacturing employment as a proportion of total employment: 6.4% in 2018
Fostering innovation	• Set target of creating 1.5 million jobs outside agricultural section between 2017 and 2024.
	• Policy and regulatory reform to facilitate business start-ups Rwanda ranked 2nd in Africa by WD Doing Business Report 2027
	• Increased budget allocation for R&D in technology and industrial development

Source: Author' compilation with insights from Rwanda VNR GoR (2019b)

CHAPTER 3

STI System, Policy Frameworks and Governance

"…in Rwanda, our urbanisation rate is around 6% a year, compared to the global average of around 2%. In 1962, Rwanda's capital, Kigali, had only around 6,000 residents. Today, Kigali is home to nearly 1.5 million people. Still, less than 20% of Rwanda's population lives in urban areas. Our target is to raise that to 35 percent in the coming years…We cannot afford to leave urbanisation to chance or go back and fix mistakes later after costs and damage have already been incurred. This is where technology has a huge role to play"

H.E. Paul KAGAME,
President of the Republic of Rwanda, Doha,
30 October, 2019[1]

3.1 STI Ecosystem: Actors and Decision-making Processes

3.1.1 Actors, roles, responsibilities

The NCST, a key factor in Rwanda's science, technology, innovation (STI) ecosystem, has the mandate of advising the government on policies and legislations on STI and research (STIR). In addition, the NCST, undertakes the monitoring of policies and legislation in the areas of STIR. In addition to the NCST, the following are selected examples of other major sector-level actors in technology (and S&I) governance

- Ministry of ICT and Innovation (MINICT): MINICT was created in 2019, which partly demonstrates Rwanda's belief in promoting ICT and digital technologies as innovation drivers to underpin national social and economic development towards achieving Rwanda's Vision 2050 (MINICT, 2017; Daniels, 2020; Twiringiyimana et al., 2021).
- Ministry of Trade and Industry (MINICOM): Through the Rwanda's National Industrial Research and Development Agency (NIRDA), Rwanda has significantly invested in technology research and acquisition in support of value-addition to manufacturing of diverse products including dairy, honey, banana, potato, and ceramics. In addition, Rwanda plans to establish at least one factory per each of the thirty district, with a focus on increasing value-added products from locally available row materials, skills 'and other sets of competitive advantages by 2021' (Chataway et al., 2019).
- Ministry of Education (MINEDUC): The Higher Education (HE) and training system is predominantly STEM, with 80% of government sponsored undergraduate students enrolled in STEM domains, including TVET. The aim is party to produce skilled graduates to drive the aspired industrial sector (Chataway et al., 2019). The consolidated public HE system under the University of Rwanda (UR) and Rwanda Polytechnic (RP), dominated by STEM and TVET programmes respectively, demonstrates the role of MINEDUC in technology capacity and skills development (Twiringiyimana et al., 2021).
- The Ministries of Health (MoH), Agriculture and Animal Resources (MINAGRI) and Environment (MoE), host sector-specific agencies that conduct research and technology development namely Rwanda Biomedical Centre (RBC) and Rwanda Agriculture and Animal Resources Board (RAB). The MoE host a specialised funding mechanism for technology and innovation in climate change and environment geared at Rwanda's green growth. This fund is named Rwanda Green Fund (FONERWA) (GoR, 2020b).

3.1.2 Decision-making processes

Recent studies affirm that STI has retained its strategic position within Rwanda's governance circle, although the country has not had a specific ministry for science and technology for over a decade (Twiringiyimana et al., 2021). In addition, technology is embedded into STI policy i.e., no dedicated national technology policy. Technology activities are broadly coordinated and regulated by the National Council for Science and Technology (NCST) (Daniels, 2020). The implications of the absence of a ministry dedicated to STI and the ways that oversight of STI by a Council (NCST) affect the policy processes and decision-making on STI are key factors that must be considered.

For the purposes of decision-making on STI policy, the Minister of Education is by law the co-chair of the NCST Governing Council (Twiringiyimana et al., 2021).

1 President Kagame's Remarks at the Opening of Qatar IT Conference & Exhibition Smart Expo https://www.paulkagame.com/president-kagames-remarks-at-the-opening-of-qatar-it-conference-exhibition-smart-expo-doha-30-october-2019/

This in part implies that the Minister of Education is mandated to table all NCST policies, strategies and programmes that require approval to the Cabinet. For sector specific policies, strategies, and programmes such as agriculture and manufacturing, respective ministries, that is, MINAGRI for the former and MINICOM for the latter are the Ministries mandated to submit relevant files which need to be approved by Cabinet. Part of the requirements for Cabinet submission include evidence on whether relevant stakeholders have been consulted. This is conducted by the office of Prime Minister whose role includes the coordination and monitoring of government policies as discussed in section 2.2.3 above.

The creation of Ministry of ICT and Innovation (MINICT), on the one hand demonstrates Rwanda's political aspirations for digital technology and innovation-driven development (Twiringiyimana et al., 2021) and attaining the status of Africa's ICT hub[2]. On the other hand, 'this shift implies a change of innovation policy coordination role, with implications on the mandate and activities of NCST' (Daniels, 2020, p. 26). In this vein, the political economy of Science Granting Councils (SGCs) study recommends 'strengthening of policy synergies and identification of interrelationships and trade-offs among the goals' (Daniels, 2020, p. 27). Relatedly, more recent studies highlight the need for 'specialised capacity building schemes' and targeted creation of linkages between academia, government, and industry, through Triple Helix (TH) framework. Strengthening of linkages among STI actors are paramount if Rwanda is to develop internal capabilities of generating technologies that are responsive to the country's societal needs (Yongabo, 2021a).

As outlined in Section 1 and preceding paragraph, this STI review and TNA emphasises strong interaction among government, academia, and industry, in line with the TH and NSI frameworks. Therefore, besides the key STI actors in government and academia, industry stakeholders are active in Rwanda's STI ecosystem. Some of the main industry actors are outlined in the NSI mapping later in this section – see Figure 6 (STI Systems (NSI) Mapping: Main Actors and Stakeholders). Figure 3 illustrates Rwanda's STI Policy landscape, showing the alignment of STI priority sectors with the national, regional, and global development visions and strategies. The figure helps to demonstrate the extent to which the STI policy priority sectors cover (or help to achieve) the pillars of NST1 and Vision 2050.

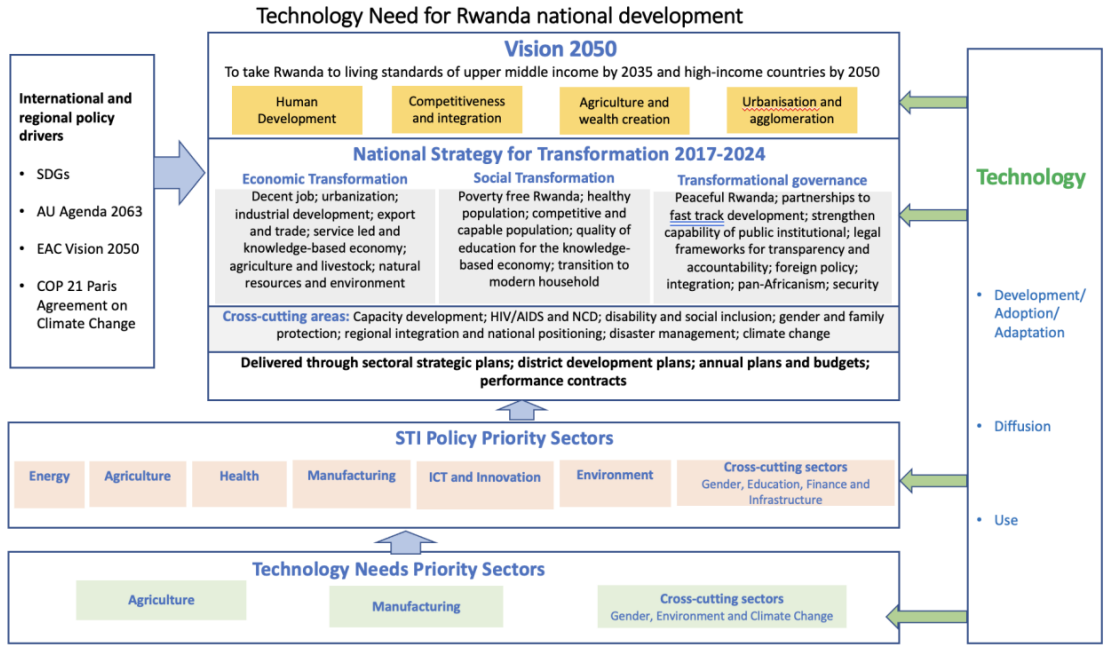


Figure 3. Rwanda STI policy landscape in relation to national development agenda *Source: Author' compilation, adapted from GoR (2020b, p. 3)*

2 See for example, ICT Sector Strategic Plan 2018-2024

3.2 STI Ecosystem: Analyses of Performance

In this section, we analyse the performance of Rwanda's STI ecosystem. With reference to the available data, we discuss Rwanda's performance on key STI indicators, in comparison to other countries in the region (Burundi, Democratic republic of Congo-DRC, United Republic of Tanzania, and Uganda), at SSA level (South Africa) and beyond the African continent (India, Singapore and the United Kingdom (UK)). Some of the traditional indicators used in the field of STI include:

- GERD (Gross Expenditure on R&D),
- BERD (Business Expenditure on R&D),
- GovERD (Government Expenditure on R&D),
- GBAORD (Government Budget Appropriations or Outlays for R&D),
- PSERD (Public Sector Expenditure on R&D), and
- HERD (Higher Education Expenditure on R&D);
- Education, capabilities, and skills; also,
- Number FTE researchers per million. In this STI review and TNA report, we compare this with countries in the East African Region and selected international cases e.g., Singapore, UK, India,
- Publications and citations,
- Patents,
- Number of innovation hubs and tech start-ups, and related FDIs
- Others, relevant rankings – include Global Innovation Index (GII)[3], competitiveness, digital readiness, global entrepreneurship, World Bank's Ease of Doing Business, ICT (for example, internet affordability index[4]).

Based on some of the indicators populated in Table 5, Rwanda's STI ecosystem performance is classified into three categories (Above Average, Mid-range, and Below Average) based on how Rwanda is ranked in relation to other counties:

- **Above Average** (where Rwanda is doing well, comparatively, but needs strengthening): Gross domestic expenditure on R&D (GERD) as percentage of Gross domestic product (GDP) (0.69); Government expenditure on R&D (GOVERD) as % of total GERD (77.76), number of innovation hubs (support to Tech start-ups) (10); and Ease of Doing Business (38 out of 190 nations). For instance, Rwanda GERD as % of GDP is higher than that of all other countries in the region, and slightly below South Africa. The GOVERD as % of total GERD of 77.76% is by far the highest of all countries on the list. One implication of this high rate of GOVERD as % of total GERD is that Rwanda government is more research intensive when compared to other countries, including some high-income countries (see Table 5). Regarding the Ease of Doing Business indicator, Rwanda is ranked 38, making it 2nd on African continent following Mauritius which ranks 13. Singapore ranks 2nd globally.
- **Mid-range** (where Rwanda is doing ok, on the average levels of performance, but needs improvement): Rwanda's Business expenditure on R&D (BERD) as % of total GERD (6.83) is higher than that of Uganda (4.34) but lower than Burundi (8.81) and South Africa (40.95). This indicator is much higher for Singapore (59.69) which partly means that Rwanda's policy and regulatory environments, policies and policy instruments need to be improved to foster private sector investment in R&D if Rwanda is to mirror Singapore's economic growth pathways, as aspired. The percentage of Female number of FTE researchers per million inhabitants (27.54) is higher than other countries in the region except Uganda. However, improvements are needed to reach the level of South Africa (44.42), which is the most research extensive country in Africa as submitted by Twiringiyimana et al. (2021).
- **Below Average** (Figure 4[5] where Rwanda is performing below expectation and require drastic improvements): For indicators such as Research Output as percent (%) of

3 WIPO (2020) Global Innovation Index 2020, Available at: https://www.wipo.int/edocs/pubdocs/en/wipo_pub_gii_2020/rw.pdf

4 A4AI (2021) The A4AI Affordability Report, Available at: https://a4ai.org/research/affordability-report/

5 World Economic Forum (2019) The Global Competitiveness Report 2019, Available at: http://www3.weforum.org/docs/WEF_TheGlobalCompetitivenessReport2019.pdf

Africa (0.48) (see Table 5); Number of FTE researchers per million inhabitants (13.86); HERD as % of total GERD; World ranking in Knowledge & Technology outputs (2020) (103 out 131 countries); and Patent applications (1), Rwanda ranks among the least performing countries in the region and globally. For instance, the WIPO GII 200 ranks Singapore 14th out of 131 in Knowledge and Technology outputs. This in part implies that drastic improvements in research and innovation capacity development are imperative for Rwanda to achieve the aspired economic transformation. Special emphasis needs to be put on research-intensive universities – as main sources of research and knowledge production in the country. In the same vein, Rwanda needs to make far-reaching improvements on STI policy instruments and policy mix to stimulate and facilitate technology development that result in increases in patent applications.

A summary of other STI ecosystem performance analysis on Rwanda, based on the indicators outlined above, is presented in Table 5.

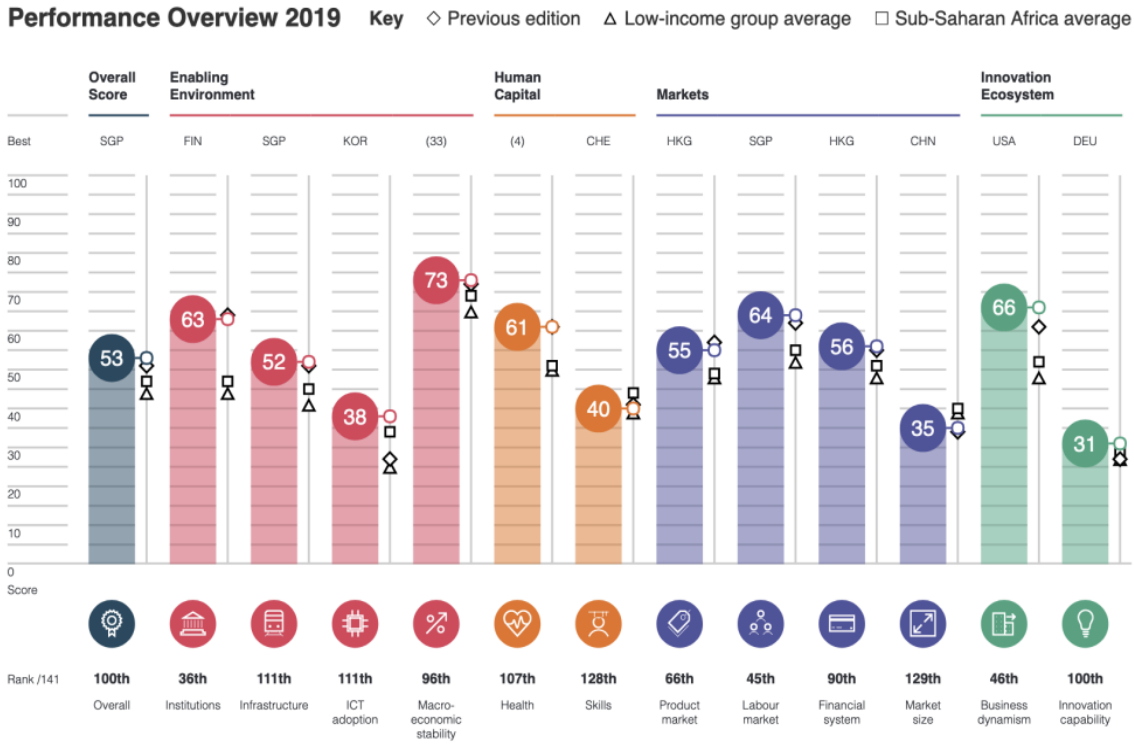


Figure 4. Global Competitiveness Index – Rwanda, 2018-2019 *Source: WEF, World Competitiveness Report 2018-2019*

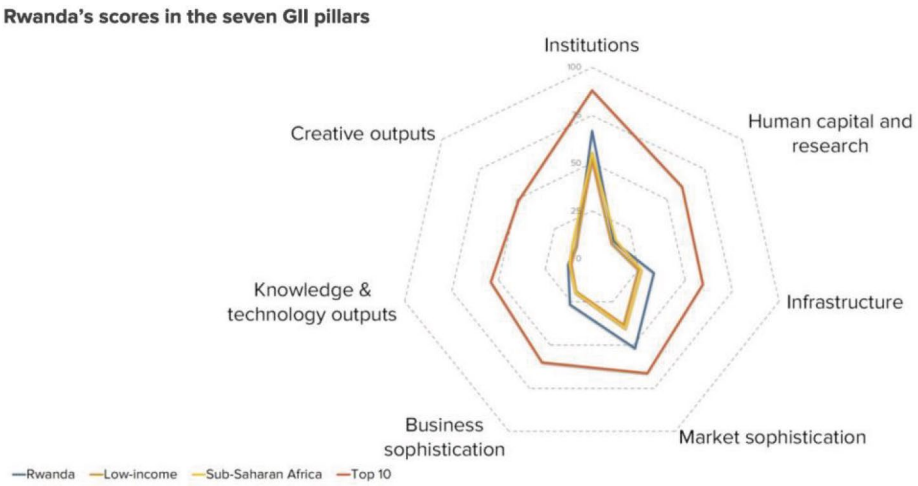


Figure 5. Benchmarking Rwanda against other Low-Income economies and Sub-Saharan Africa *Source: Global Innovation Index (GII) 2020, WIPO*

Table 5: Education, Capabilities, and Skills, and STI Indicators

Indicator 2019	Rwanda	Burundi	DRC	Tanzania	Uganda	South Africa	Singapore	India	U
Total population (in thousands)	12,627	11,531	86,791	58,005	44,270	58,558	5,804	1,366,418	67,530
People aged 14 years and younger as % of the total population	40	45	46	44	47	29	12	27	18
Government expenditure on Education as % of GDP	3.07 (2018)	5.08 (2018)	1.45 (2017)	3.7 (2018)	2.13 (2018)	6.51 (2019) 6.16 (2018)	2.85 (2013)	3.84 (2013)	5.44 (2017)
Government expenditure on Education as % of total government expenditure	10.08 (2018)	18.8 (2018)	14 (2017)	20.5 (2018)	11.5 (2018)	19.6 (2019) 18.9 (2018)	28.8 (2013)	14.1 (2013)	13.8 (2017)
Literacy rate among the population aged 15 years and older (Total)	73.2 (2018)	68.4 (2017)	77.0 (2016)	83.2 (2015)	76.5 (2018)	87.7 (2017)	97.3 (2018)	74.4 (2018)	-
Literacy rate among the population aged 15 years and older (Female)	69.4 (2018)	61.2 (2017)	66.5 (2016)	73.1 (2015)	70.8 (2018)	86.5 (2017)	95.9 (2018)	65.8 (2018)	-
Number of FTE researchers per million inhabitants	13.86 (2016)	23.44 (2018)	10.56 (2015)	19.15 (2013)	27.84 (2014)	517.72 (2017)	6,802.54 (2017)	252.70 (2018)	4,603.31
% Female of FTE researchers per million inhabitants	27.54	14.32 (2018)	10.06 (2015)	24.52 (2013)	28.13 (2014)	44.42 (2017)	-	16.60 (2018)	-
GERD as % of GDP	0.69 (2018/9)[6]	0.20 (2018)	0.40 (2015)	0.50 (2013)	0.10 (2014)	0.80 (2017)	1.90 (2017)	0.70 (2018)	1.70 (2018)
GOVERD as % of total GERD	77.76	53.45	3.94	38.65	47.09	22.31	10.97	56.11	6.11

6 Increased from 0.66% in 2015/2016 to 0.69% of GDP in 2018/2019 (Source: NCST, 2021. Analysis Report: Rwanda National Research and Experimental Development (R&D) Survey for 2018/2019).

Indicator 2019	Rwanda	Burundi	DRC	Tanzania	Uganda	South Africa	Singapore	India	UK
HERD as % of total GERD	7.88	11.31	93.66	61.35	45.99	33.60	29.34	7.10	22.54
PNPERD as % of total GERD	7.52	26.43	2.41	-	2.58	3.14	-	-	2.22
BERD as % of total GERD	6.83	8.81	-	-	4.34	40.95	59.69	36.79	69.13
H-Index	88	45	66	175	184	468		624	1487
Publications (documents)	3698	742	1308	19678	19550	303863		1873277	3715590
Citations	62159	11118	23354	363861	379857	4434473		18243852	89357199
Citations per document	16.81	14.98	17.85	18.49	19.43	14.59		9.74	24.05
Research output as % of Africa	0.48	0.08	0.25	1.88	1.87	25.55		-	-
Number of Innovation Hubs [support to (tech) start-ups][7]	10	-	11	23	10	78	-	-	-
World ranking in Knowledge & Technology outputs (2020)[8] (GII, 2020)	103	-	-	106	113	62	14	27	9
Ease of doing business[9]	38	166	183	141	116	84	2	63	8
Patent applications by office and origin (2019)	1	7	87	8	2	1,514	7,354	34,015	54,762
Research Output as % of the World[10]	0.02	0.00	0.01	0.06	0.06	0.85		5.72	6.5

Source: AUDA-NEPAD (2019); WIPO (2020b); Twiringiyimana et al. (2021)

7 https://briter-bridges.typeform.com/to/WhIxAm pp. 6 [Accessed: 19.03.2021]

8 Global Innovation Index (GII), https://www.wipo.int/global_innovation_index/en/ pp. 16-17 [Accessed: 24.02.2020]

9 The WB, Doing Business 2020 https://www.doingbusiness.org/en/rankings [Accessed: 24.07.2021]

10 Scimago Journal & Country Rank, https://www.scimagojr.com/countryrank.php

3.3 Key STI Programmes and Strategic Interventions

In analysing the STI ecosystem, it is important to examine some of the key STI programmes and strategic interventions as these provide useful insights on, for example, the policy instruments and policy mix being adopted, why, and the main actors and stakeholders involved in the implementation. The NST1 is discussed below as an example of STI policy with individual pillars (programmes) and strategic interventions.

NST1 Priorities, associated strategic interventions, main actors, and stakeholders:

For each of the four NST1 pillars, priorities are associated with key strategic interventions alongside main stakeholders (GoR, 2017a, pp. 12, 65–77). The NST1 priorities are articulated under four pillars namely:

(i) Economic transformation pillar

To accelerate private sector-led, knowledge-based and Rwanda's natural resource-based inclusive economic growth and increased productivity. The focus is on seven priority areas:

a. Creating 1,500,000 (214,000 annually) decent and productive jobs for economic development.
b. Accelerate sustainable urbanisation from 18.4% (2016/17) to 35% by 2024.
c. Establishing Rwanda as a globally competitive knowledge-based economy. Key strategic interventions include: Developing and operationalizing a thriving skills ecosystem for attracting local and international talent around the Kigali Innovation City (KIC); Operationalizing the innovation fund to support firms in the innovation and technology industry; Ensuring digital literacy for all youth i.e. people aged 16-30 and at least 60% of adults by 2024; Supporting the creation and operationalisation of new and existing centres of excellence with focus on STI; and Promoting R&D to fast-track Rwanda's economic transformation, particularly in technology for industrial development (GoR, 2017a, p. 19). Stakeholder/responsible institutions: Ministry of Education (MINEDUC) (Lead); Ministry of ICT and Innovation (MINICT); Rwanda Development Board (RDB); Private Sector Federation (PSF); Ministry of Infrastructure (MININFRA); Rwanda Development Bank (BRD); University of Rwanda (UR); National Bank of Rwanda (BNR); and, Rwanda Governance Board (RGB) (GoR, 2017a, p. 67).
d. Promoting industrialisation and attaining a structural shift in the export base to high-value goods and services with the aim of growing export by 17% annually Key strategic interventions include: Creating and expanding industries in collaboration with the private sector, to promote locally produced materials as part of "Made in Rwanda" policy; Identifying and developing priority value chains: to be achieved through identifying and proactively attracting well established firms (with market linkages) for each of the following priority economic value chains; Undertaking big shift in Rwanda's export outlook; and Developing a vibrant aviation sector, including creation of a centre of excellence in aviation, to develop critical skills in that sector (GoR, 2017a, p. 20). Stakeholder/responsible institutions: Ministry of Trade and Industry (MINICOM) (Lead); Rwanda Development Board (RDB); Private Sector Federation (PSF); MINICT; Ministry of Finance and Economic Planning (MINECOFIN); Rwanda Development Bank (BRD); and Rwanda Capital Market Authority (CMA) (GoR, 2017a, p. 67).
e. Increasing domestic savings and positioning Rwanda as a hub for financial services to promote investments.
f. Modernizing and increasing the productivity of agriculture and livestock.
g. Promoting sustainable management of the environment and natural resources to transform Rwanda towards a Green Economy.

(ii) Social transformation pillar

To develop Rwandans into a more capable and highly skilled individuals with quality standards of living and a stable and secure society, through five priority areas:

a. Promoting resilience and enhancing graduation from poverty and extreme poverty – with the aim to eradicate extreme poverty by 2024
b. Eradicating malnutrition
c. Enhancing demographic dividend through ensuring access to quality health for all. Key strategic interventions include: Promoting industries in pharmaceuticals and manufacturing of medical equipment and support medical research. To be achieved through attracting and supporting identified industries, and through sector specific incentives. The aim is to enhance competitiveness and expansion, investing in capacity building and supporting technology acquisition and upgrading (GoR, 2017a, p. 29). Stakeholder/responsible institutions: Ministry of Health (MoH) (Lead); Rwanda Biomedical Centre (RBC); MINICOM and RDB (GoR, 2017a, p. 71).
d. Enhancing demographic dividend through improved access to quality education Key strategic interventions include: Increasing the use of ICT in teaching and learning through scaling up SMART classrooms and ICT devices in schools; Promoting further technical and vocation education and training (TVET) i.e., increase TVET enrolment share from 31.1% in 2017 to 60% by 2024; and Promoting Science, Technology, Engineering and Mathematics (STEM) education at all levels of education. The goal is to increase higher education enrolment in STEM and TVET from 59.3% in 2017 to 80% by 2024 (GoR, 2017a, p. 31). Stakeholder/responsible institutions: MINEDUC (Lead); MININFRA; Ministry of Gender and Family Promotion (MIGEPROF); and Rwanda Education Board (REB) (GoR, 2017a, p. 72).
e. Moving towards a modern Rwandan household

(iii) Transformational governance pillar

To consolidate good governance and justice as building blocks for equitable and sustainable national development. To be achieved through six priority areas:

a. Reinforcing Rwandan culture and values as a foundation for peace and unity
b. Ensuring safety and security of citizens and prosperity
c. Strengthening diplomatic and international cooperation to accelerate Rwanda and Africa's development
d. Strengthening justice, law, and order
e. Strengthening capacity, service delivery and accountability of public institutions
f. Increasing citizen's participation, engagement, and partnerships in development

Cross-cutting areas

Seven cross-cutting priority areas, to help ensure the attainment of inclusive and sustainable development, are outlined alongside the pillars. They are:

a. Capacity development
b. HIV/AIDS and Non-communicable deceases
c. Disability and social inclusion
d. Gender and family promotion
e. Regional integration and international positioning
f. Disaster management: Key interventions to focus on key sectors including agriculture, infrastructure, education, environment and natural resources, information and communication technology (ICT), health, the private sector and youth and social protection (GoR, 2017a, p. 44).
g. Environment and climate change

Section 3.4 that follow discuss some of the key STI policy governance and instruments utilised in Rwanda. The discussion and examples provided help to deepen the readers understanding of the policy instruments used for technology development, adaptation, adoption, and dissemination in Rwanda. In addition, the policy instruments provide useful insights on the STI ecosystem, actors, stakeholders, interactions, and linkages.

3.4 STI Governance and Policy Instruments[11]

The performance of the NSI and success (or failure) of STI policy framework is fundamentally contingent on the extent to which the national policy mix is articulated (Matusiak et al., 2021). A study examining the evolution of policy mix in the UK and Finland – including mapping of policy gaols and instruments – to stimulate 'reductions in energy use' suggests that interlocking complex policy mix is paramount for efficiency (Kern et al., 2017), which is achieved in part through the application of effective technologies and practices. Drawing on the case of 'offshore wind company in Germany', the German offshore policy mix was found to be central to steer, redirect and accelerate technological change. This was essentially achieved through adopting policy decisions based on 'a comprehensive and consistent instrument mix' (Reichardt and Rogge, 2016).

The aforementioned findings on impact of policy mixes to (technological) innovation partly resonate with Flanagan's influential work on' reconceptualization of policy mix for innovation', suggesting that policy mix interactions can be manifested through three spheres namely: dimensions in which the interactions occur, possible types of interactions (instruments between and/or across dimensions), and possible sources of tensions between instruments in the policy mix (Flanagan et al., 2011, p. 17). However, the evolution of policy mixes differs based on the characteristics of country specific STI policy framework (Kern et al, 2017). Table 6, present selected examples of existing policy instruments for technology development, adaptation, adoption, dissemination and use in Rwanda. The table is not an attempt to present an exhaustive list, rather a selection of policy instruments grouped under five categories: i) Policies and Regulatory frameworks, ii) Financial instruments, Education, and skills instruments, iii) Capabilities and skills instruments, iv) Governance and information instruments and v) Covid-19 response policy instruments – an ongoing pandemic, hence the policy mix is still under development and evolving.

Adequate 'policy mix' is imperative for the regulatory framework and policy instrument 'portfolio' to function and harness technology [and S&T] for national development.

3.5 STI System Mapping: Main Actors and Stakeholders in the NSI

Building on the preceding discussions in this section that unpacked the STI policies, programmes, interventions and the actors and stakeholders responding for the implementation of the various interventions using specific policy instruments, Figure 6 provides a representation (mapping) Rwanda's STI ecosystem. The STI Systems (or more broadly, NSI) mapping highlight the main actors and stakeholders, focusing on:

- Government: Policymakers
- Academic: Research, Knowledge and Skills Producers
- Industry: Innovation practitioners in firms and M/SMEs such as innovators and digital tech start-ups and entrepreneurs
- Innovation Intermediaries and Service Providers

3.6 STI Systems SWOT Analysis

3.6.1 Strengths, Weaknesses, Opportunities and Threats Analysis of Rwanda's STI System

The STI-related strengths, weaknesses, opportunities, and threats (SWOT) for Rwanda, are presented below in this section. The SWOT analysis draw from secondary data, the preceding discussions and evidence from workshops and interviews conducted between April and August 2021. Table 7 presents a summary of the SWOT.

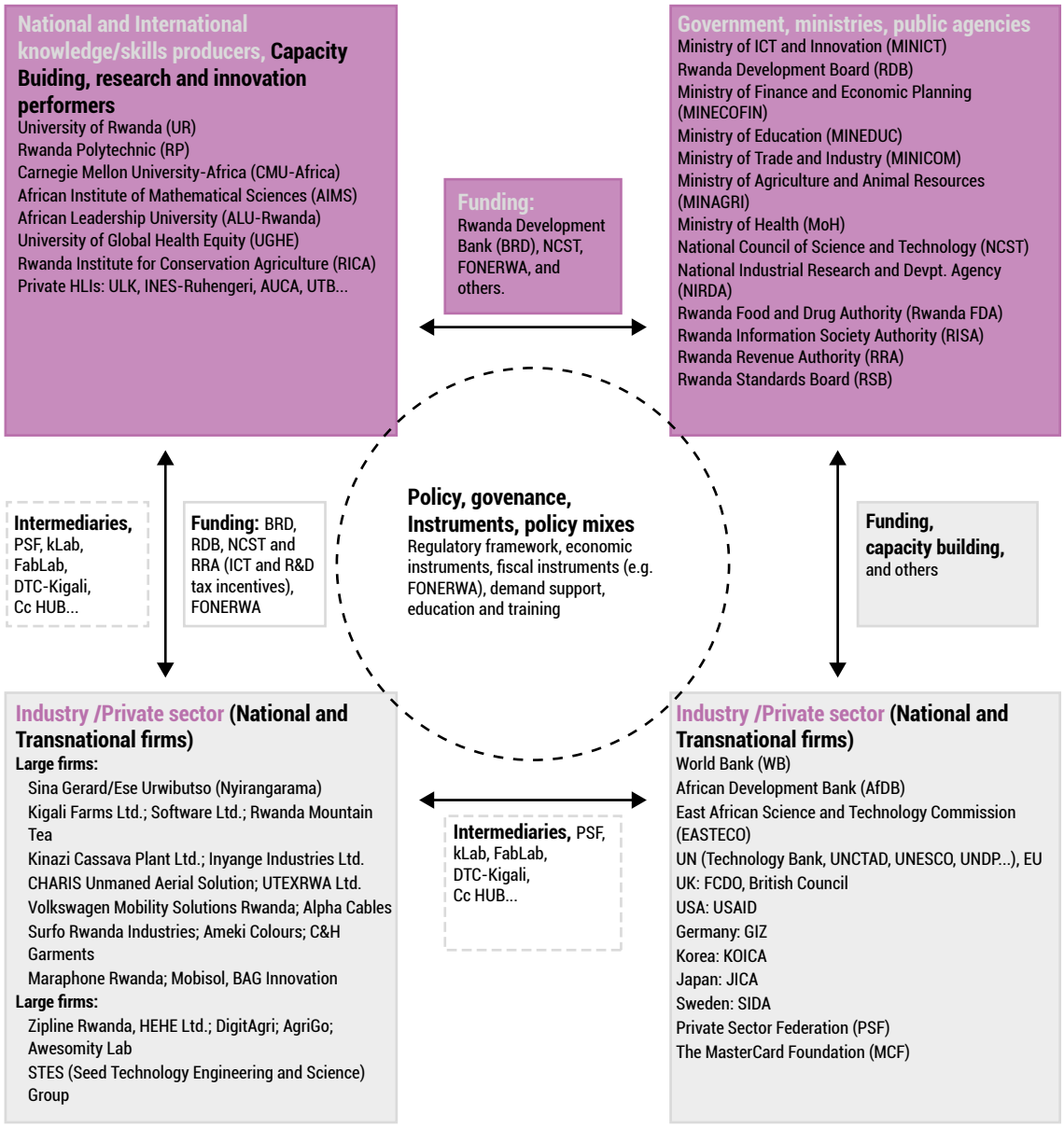
11 STI Policy 2020 (pp28-29) mentions STI policy instruments (legislative, regulatory and funding instruments)

3.6.2 Key insights from the SWOT Analysis

The SWOT analysis takes a broad perspective. It covers the NSI, research and policy systems in Rwanda. Key insights from the SWOT analysis include: 1) Strengths – high level government support, presence of relevant policies and the ease of doing business in Rwanda; 2) Weaknesses – that relate to the governance of STI systems, policies, and interactions NSI stakeholders and low investments.

The SWOT analysis also outline Opportunities that can be harnessed in relation to STI include and Threats that should be mitigated or eliminated for the NSI and STI systems to deliver on their optimum potentials. As the sections that follow show, the findings presented in the SWOT analysis are relevant to the TNA sectors – Agriculture and Manufacturing, to improve the findings of the report and ensure context specificity.

Figure 6. STI Systems (NSI) Mapping: Main Actors and Stakeholders[12]. *Source: Author*



12 May be revised to include the Global Science Supply and Global Technology and Innovation Supply, as part of International STI Supply. Reference to Fig 3.2 (pg.47) of Guidebook on STI for SDG Roadmap

Table 7: Rwanda STI SWOT Analysis

Strengths that should be better utilised	**Weaknesses** to be addressed, urgently
• High-level support for STI by Government – as expressed in relevant policies and regulations • A favourable Governance structure that places STI at the presidency. In this governance structure the NCST oversee STIP while sectoral Ministries cover policies and strategies focused on individual sectors, in alignment with Vision 2050 • Presence of key policies, instruments, and institutional frameworks to foster STI – e.g., STIP, Made in Rwanda, National ICT Strategy, and others. • Presence of key NSI actors and stakeholders in institutions such as, NCST, RAB (Rwandan Agric Board), NIRDA (for Manufacturing), RISA and others • Investments in STI, especially in research, BERD, GERD, GOVERD as % of total GERD; high investments in ICT • A good Ease of Doing Business ranking, indicating a favourable climate for business, entrepreneurship, and innovation • Relatively high number of innovation hubs as a ratio of population • High ICT penetration level alongside good ICT infrastructure • Relatively strong interaction between industry and government	• Governance of STI ecosystem, actors and stakeholders and policies to foster transformative change • Interaction among NSI actors and stakeholders. High level of disconnect between academia and government, with better interaction among industry and government. Academia-industry can, for example, support joint students' supervision • Research capabilities, as expressed by the low number of FTE researchers per million inhabitants; percentage of Female of FTE researchers per million inhabitants; Government expenditure on Education as percentage of GDP; Research Output as percentage of Africa • Low Research Output as percentage of total outputs in Africa. Low research output has implication on technology and innovation • Low HERD as percentage of total GERD compared to countries in the region • Low GII ranking – World ranking in Knowledge and Technology outputs (2020) • Very low number of patent applications • Misalignments among policies – need for policy integration and alignments • Sectoral policies (e.g., to support manufacturing at sectoral levels and provide clear regulations on standardisation) weak or lacking, despite the presence of high-level policies (e.g., Made in Rwanda and STI policies)
Opportunities that should be exploited	**Threats** to be mitigated, eliminated
• Advances in research, science, innovation, and digitalisation, in the East African region, Africa and globally • Youthful age – 14 years and younger – as a percentage of the total population • TVET and Higher Education policies • Good sectoral policy environments • "Rwanda is open for business" national investment strategy • Capacity building and knowledge production, encapsulated in programmes such as the National capacity development policy, Workplace learning policy and others • Research and Innovation Agenda (by the NCST) • STI infrastructures such as African and regional Centres of Excellence in STEM including ACE and CMU-A. These centres can support research, capacity-strengthening, and innovation • Strategic location in East Africa, with many neighbouring countries • Regional markets in East Africa • Progress in integration in the continent, exemplified by the African Continental Free Trade Agreement (AfCFTA) and market	• Increased rates of unemployment exacerbated by Covid-19 pandemic • Overemphasis on attracting foreign investors (especially technology and manufacturing firms) at the expense (or low emphasis) of domestic tech start-ups • High sovereign debt (national public debt of 66% of GDP in 2020, expected to rise to about 72% of GDP in 2021 due to COVID-19 pandemic. 72% debt to GDP ratio is above safe debt ratio of 65%, according to AfDB)[13] • Dearth of capabilities and skills in STI; human resources • Low rates of STI and public policy implementation • Governance of STI policy • Inability to mobilise greater funding (FDIs especially) for STI and R&D • Low levels of digital literacy • Climate change, biodiversity loss and environmental degradation – due to, for example, high use of inorganic fertilizers by farmers

13 AfDB, Rwanda Economic Outlook (2021) https://www.afdb.org/en/countries/east-africa/rwanda/rwanda-economic-outlook [Accessed:24.07.2021]

CHAPTER 4
Technology Needs Analysis Sectors: Agriculture and Manufacturing

As outlined in the Section 2.3 above, Rwanda's National STI Policy of 2020 outline six priority areas. To reiterate, the priorities are Sustainable energy; Food security and modern agriculture; Health and life sciences; Local production and value addition; Digital services, products, and lifestyle; Environment, tourism, natural resources, and climate change (GoR, 2020b). However, for practical reasons and time constraints, it is not realistic to conduct technology analysis in all six areas. Therefore, in consultation with STI actors and stakeholders, see Annex 1, it was agreed that two priority areas – Agriculture and Manufacturing sectors – should form the basis of this Technology Needs Assessment (TNA).

Agriculture and Manufacturing sectors in Rwanda's Economy

Rwanda's Gross Domestic Product (GDP) and its structure show that in the first quarter of 2021, contributions to the GDP are as follows: services sector, 46 percent; agriculture sector, 27 percent; Industry sector, 20 percent; while 8 percent of GDP contribution resulted from adjustments in taxes and subsidies on products, see also Figure 7 (GoR and NISR, 2021).

In terms of growth rate by kind of activity, activities in Agricultural and Industry grew by 7 and 10 percent respectively, each contributing 1.7 percentage points to overall GDP growth.

Within agriculture, the production of food and export crops increased by 7 percent respectively. The main contributors in the industry sector were Construction and Manufacturing which grew by 14 and 8 percent respectively. Although the service sector accounts for the highest contributions to the GDP; Agriculture and Industry (Manufacturing) represent the second and third highest contributions to the economy. Further, the "Service sector remains at the same level of quarter one of 2020, thus 0 percent growth" (GoR and NISR, 2021, p.2). This indicates stagnation in the service sectors, thus highlighting a focus on agriculture and manufacturing as sectors with growth potentials and opportunities for transforming the Rwandan economy. Box 2 helps to illustrate the linkage and interdependencies between agriculture and manufacturing. Progress in manufacturing – for example, improvements in processing and packaging – is essential to achieving gains in agriculture, such as increased productivity and financial returns to farmers.

4.1 Priority Sector 1: Agriculture

4.1.1 Priority sector explained and summary of workshop findings

As discussed above, Agriculture remains one of the leading sectors in Rwanda and a major contributor to the GDP. Agriculture also holds significant potentials for transformation in terms of economic prosperity that includes

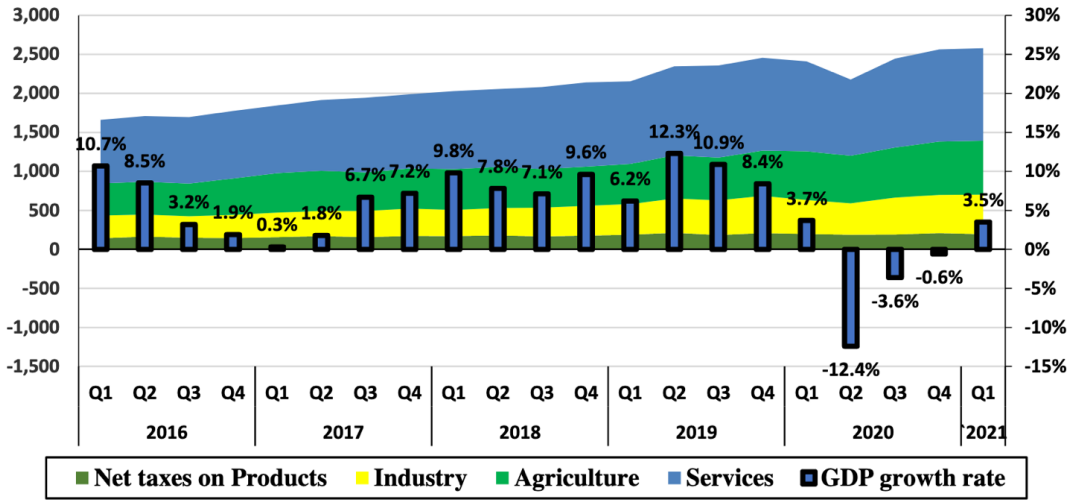


Figure 7. Gross Domestic Product Structure and Growth rate. *Source: Gross Domestic Product – 2021 Q1, Government of Rwanda, National Institute of Statistics of Rwanda (NISR), June 2021 - https://www.statistics.gov.rw/publication/1695*

Box 2: Linking Agriculture and Manufacturing

The growth in Manufacturing activities in Rwanda's Q1 GDP figures, is due to an increase of 7 percent in food processing, 17 percent in Wood & paper; printing, 29 percent in Metal products, machinery and equipment, and 20 percent in production of Chemicals and plastic products. However, Textiles, clothing & leather goods and Non-metallic mineral products declined by 2 percent and 3 percent respectively.

Source: Gross Domestic Product – 2021 Q1, Government of Rwanda, National Institute of Statistics of Rwanda (NISR), June 2021 - https://www.statistics.gov.rw/publication/1695

job creation and employment opportunities. In addition, Agriculture has direct bearing on addressing social (e.g., reductions in inequality and enhancing inclusion, especially with respect to women, youth, and communities in the rural areas or marginalised) and environmental challenges ranging from climate change to biodiversity losses. This next section outlines some of the needs in Agriculture sector, barriers and challenges alongside the enabling environment and opportunities for transformation.

Sectoral Workshop on Agriculture July 2021: Summary of findings

A key goal and mission of the Government of Rwanda is to move from subsistence to knowledge-based and sustainable agriculture and food system[1]. However, stakeholders stated that a major barrier to achieving this goal is limited access to information, for example, on crop production strategies, tools, and technologies[2]. Technology was identified and emphasized to be essential for addressing the gaps in information access, alongside ensuring quality improvements and controls in agriculture and food systems. For example, rural farmers need to transport their produce to Kigali, the capital city. Effective deployment of technologies in the processes involved can help maintain, improve, and control quality of agriculture and food products, thereby ensuring better price and income for farmers at the target destinations. The need for effective technologies to increase productivity (yield) on relatively small unites of land was also emphasized.

Many farmers in Rwanda are small, based in the rural areas and engaged in subsistence farming[3]. A large proportion of farmers in this group are women, highlighting a strong gender dimension with implications on the SDGs[4]. A segment of the farmers population is illiterate; access to information for this group is a major challenge. Technologies such as smart phones and VORs –voice over radios, could be used to provide the relevant information to the different types of small holder farmers based on their education/literacy levels. Despite the positive policy environment, this demography and characteristics of the agriculture and food sector highlight barriers and challenges. Technology adoption can help address the barriers and challenges identified and foster transformation.

Therefore, aspects where technology could support further developments in Agriculture include:

1 Ministry of Agriculture and Anima Resources, Rwanda (2018). Strategic Plan for Transformation of Agriculture, http://extwprlegs1.fao.org/docs/pdf/rwa180543.pdf

2 In addition to "better weather and climate information and early warning and seeks to ensure all investments are climate smart", "market information" (p.10), information "on regulations, soil and climatic conditions, market information, costs of inputs and labour and information on processes and key institutional stakeholders for investment" (p.25) and others including capacity development and training, credit provision, (Strategic Plan for Agriculture Transformation).

3 "75% of Rwanda's agricultural production comes from smallholder farmers" https://rdb.rw/investment-opportunities/agriculture/

4 "…more than 70 per cent of Rwandan women are engaged in farming activities since their childhood. Yet, they don't have the same access to land, production inputs, finance or markets as men. As a result, women farmers are mostly relegated to subsistence farming" https://www.unwomen.org/en/news/stories/2018/10/feature-empowering-women-farmers-in-rwanda. See also, for example: http://gmo.gov.rw/rw/fileadmin/user_upload/profiles/Gender_Profile_in_Agriculture__GMO__March_2017.pdf; https://www.statistics.gov.rw/publication/seasonal-agricultural-survey-season-2021; http://www.fao.org/rwanda/our-office-in-rwanda/rwanda-at-a-glance/en/

a. Increasing productivity (yield) on limited (existing) farmlands
b. Processing, packaging, storage, value addition, and information and knowledge sharing
c. Manufacturing and production, in the various stages involved, including:
    - Pre-cultivation
    - Cultivation
    - Post cultivation
d. Reducing Post-Harvest Losses
e. Precision agriculture, monitoring a1nd related activities
f. Biotechnology

Other important findings

- There was strong emphasis on the need for increased efforts that are focused on linking value chain actors – farmers, shop owners, buyers, manufacturing and production actors and others. Stakeholders called for a "system of linkages" to be put in place to ensure connectedness of all value-chain actors in a particular product. This would include: i) identifying who are the actors; ii) how they can be linked for the benefit of the [small holder] farmers. This finding highlights the importance of strengthening the Sectoral Systems of Innovation in Agriculture and Food Systems.
- Another value chain grouping that emerged: farmers – intermediaries – consumers. It was noted that intermediaries were responsible for a large share of increases in sales price of farm agricultural products, resulting in less income for farmers. An example was given in which a produce sold for 50F (Rwandan Franc) by a farmer eventually sells for about 120F at market price. The argument was that if technology could be deployed to help connect farmers directly to buyers, that would help reduce additional costs added by intermediary actors and increase farmers profits, income, and wellbeing. The proposed technologies may include creating farmer clusters based on their products and locations and provide them with technology platforms allowing them access to end-market information. This information would form the basis/evidence for the farmers to determine (or at least contribute to determining) the price of their produces.
- The preceding points also resonate with the need for better information circulation – for example, in relation to price fluctuations, how farm product/produce are evaluated, and the criteria used in the processes involved, or how costs of production and sale prices are calculated.
- For e-business, market segmentation low technology such as phone SMS could be used, if capacity building and digital literacy programmes for farmers are deployed. However, for areas such as agriculture mechanization and irrigation, high tech will be much needed such as IoT and AI for prediction and analysis both the products and markets. Identifying low tech and high tech needed by different segments of agriculture system would be vital.
- Stakeholders raised the point on youth and employment. "How do we engage, attract, and retain the youth in agriculture?" And emphasized that "Knowledge-based agriculture is precision agriculture – requires technology deployment".
- This is vital to realizing the strategies and visions of Rwanda's government and addressing the SDGs and leaving no one behind, in line with the Agenda 2030 of the UN. What roles could technology play?
- Current market structure is broadly made up of:
    - Government-owned farms and farmers: High tech such as precision agriculture could start with these relatively big spaces (farmlands)
    - Co-operatives – farmers who have consolidated their farmlands and are able to, more effectively, deploy technologies
    - Individual farmers who are predominantly at the subsistence level of farming

Related to market structure, "There is need to maximize the use of current tech/tools that we already have – e.g., telephones, radios, TV or community workers". This was mentioned by stakeholders as alongside the issue of

Table 8: Summary of Technology needs, barriers, and challenges in Agriculture

Focus area	Technology needs: echnologies for...	Barriers and challenges with respect to specific needs	Possible technology solutions and opportunities for transformation
Productivity increase: pre-cultivation	Info and data gathering, modern farming techniques, land preparation	Weak access to relevant information (e.g., on modern farming methods), finance, resources (e.g., land) and infrastructure, etc	Mobile/cell/smart phones; Techs for soil analyses; Network and platform(s) for info/data gathering and sharing; Modern farm machinery, access to finance, policy support
Productivity increase: cultivation	Enhancing crop yield by e.g., reducing production costs, and optimising infrastructure (for example, energy and water) and logistics; smart irrigation, etc	Low productivity; poor access to STI, info/ICT, data and knowledge on modern farm practices and techniques; resource, capabilities, and skills constraints; and others	Precision / smart agriculture techs, green house, smart irrigation, soil, water and land management, solar energy. Examples: Greenhouses, Drones,
Productivity increase: post-cultivation	Reducing post-harvest losses; improving storage, transportation, logistics, access to markets, price info and profitability	High post-harvest losses especially in vegetables; further losses during storage and transportation; access to markets, price info and data	Techs for storage, reducing post-harvest losses, sun/air drying, tanning, refrigeration, transportation
Animal production (Livestock farming)	Accessing technical know-how to enhance the productivity in livestock	A major loss point is milk preservation during transportation and storage	With the focus now on milk producing cows; techs e.g., for processing of milk is priority
Value addition	Adding value to raw materials e.g., in the minerals, textiles and garment, coffee supply chains and other products, before exports	Deeper analyses – which looks at the value chain – such as structural issues, market access, access to raw materials, etc	Technologies for value-addition to agricultural products and including processing, packaging, branding, marketing, transportation, and logistics
Information sharing and communicati-ons	Accessing and using farming and market info (e.g., pricing, product demand, market size, innovations in agric., capacity building exercises etc)	Farmers currently have weak access to information and knowledge that may help them increase productivity, access markets, sell their goods and enhance their well-being	Mobile/cell/smart phones, data networks; platform(s) and supporting technologies
Standardis-ation, traceability, and quality control	Ensuring standards in products, e-traceability of agriculture and food systems products, goods, and services; certifications, and quality control	Ability to ensure accurate data and information on the origins of products (e-traceability of agriculture and food), adherence to standards, certifications, and quality control by producers	Standards, such as ISO's and others applicable to foods and drugs
Finance	Finance is essential for progress in STI, R&D (formal and informal) and knowledge generation	Farmers remain one of the most marginalised groups in terms of securing formal loans	Credit-rating system (software or platform)
Capabilities and skills	Capacity strengthening e.g., on production practices (such as fertilizer application and optimisation), quality, standards, and pricing; market access and business development; and others	Weaknesses in capabilities and skills continue to hinder the adoption of emerging technologies and innovations; need to support the adoption of modern techs such as AI and blockchain	Context-specific technologies to enable capacity strengthening at low- and high-tech levels; alongside appropriate platform technologies and networks

affordability, coupled with the need of owning a smart phone for some subsistence-based farmers. Further on technologies, stakeholders enquired "How can lessons from other countries be useful for Rwanda?" For example, what can Rwanda learn from Ghana's use of drones in fertilizer application?

- A new National ICT strategy for Rwanda Agriculture (ICT4RAg) is currently being developed to replace the 2016-2020 version[5, 6]. Despite the ICT4RAg and the gains made in the past few years, stakeholders noted that:
  - A comprehensive needs assessment of the agriculture and food systems is required to help deepen understanding of the gaps in the sector, how the gaps may be addressed, and with respect to the objectives of this project, the role of technology in addressing the identified gaps
  - Financing remains a major challenge for the sector
  - There is need to bring in the private sector with investment but need to understand the return of their investment.
- The existing ICTR4Ag Strategy 2016-2020 already proposes the use of both low tech (mobile phones, radio, television, computers, and internet) and high tech (GIS, IoT) for agriculture value chain development (ICTR4Ag pg.23). The strategy states that "advances in technologies [early warning systems] such as micro sensors, GPS, GIS, mediation software, mobile phones, UVA and satellite imagery have improved stallholder's ability to adjust farms strategies and reduce risk". It would be useful to know whether the current review of this strategy provides updates on these technologies (ICTR4Ag pg.28).

ICTR4Ag (pg. 68-70) summarizes technology driven projects/programmes for Agriculture sector development, ranging from Farmer support systems: Land management information systems, Farmer/animal information systems (database), Early warning systems; Agriculture growth management system: Use of GIS and remote sensing (UVA) for precision agriculture; Greenhouse technologies; Capacity building through online farming schools modelled on massive online open course (MOOCs); and leverage existing innovation spaces such as KLab and FabLab to spur job creation among the use through fostering local capabilities in emerging technologies such as IoT and drone technologies.

4.1.2 Technology needs, barriers, challenges - Agriculture sector

Table 8 provides a summary of technology needs in the agriculture sector based on data gathered from stakeholders' workshops and interviews, complemented with secondary data from literature, reports, policies and strategies such as the Strategic Plan for Agriculture Transformation by the Government of Rwanda.

The need for adequate standards and standardisation feature strongly both in the agriculture sector analysis (Section 4.1, Table 8) and manufacturing sector (see Section 4.2 and Table 9 below). An important type of limitation to technology adoption, as noted in the Assessment of the State of STI in Rwanda is on the need to ensure adequate standards (NCST, 2021). This helps to demonstrate alignment between the findings of this report and

Annex 4 provides insights on the intersections between Agriculture Sector needs outlined above in Table 8 and technology solutions (see Section 5).

4.2 Priority Sector 2: Manufacturing

4.2.1 Priority sector explained and summary of workshop findings

A flagship policy of the Government of Rwanda designed to boost manufacturing is the Made in Rwanda (MiR) policy of 2018. Launched

5 National ICT strategy for Rwanda Agriculture (ICT4RAg) that offers critical support to rationalize and optimize financial, human and institutional resources and harness ICT4RAg opportunities to address challenges in the agricultural sector, https://imbaraga.org/IMG/pdf/ict4rag_strategic_plan_2016-2020_final__final__3_.pdf

6 However, the TNA findings do not include reflections related to the new strategy. This is because the strategy is still being developed as of the time of finalizing this report.

officially on October 25th, 2018, by the Ministry of Trade and Industry, following a prior campaign launched in 2015, the MiR Policy is aimed at "increasing competitiveness by enhancing Rwanda's domestic market through value chain development". Since its launch, the MiR policy has helped to reduce Rwanda's trade deficit by 36% and while increasing Rwanda's total exports by 69%[7]. Stakeholders noted during the workshop that "Rwanda wants to be a digital technology and manufacturing hub in Africa". To this end, various streams of investments have been dedicated to achieving this goal. Pertinent questions include, how best can Rwanda take advantage of these investments and the opportunities fostered by the MiR policy initiative? In what ways could Rwanda utilise technology and innovation (T&I) in the processes involved in the manufacturing sector? And what roles could T&I play in this regard? To what extent could Rwanda link technologies, innovations, and outcome to economic growth (for example, job creation) that is inclusive and sustainable?

Sectoral workshop on Manufacturing July 2021: Summary of findings

As discussed earlier, the MiR Policy seeks to increase manufacturing while reducing imports. Key NSI actors such as the NCST, whose mandate includes the management of the Research and Innovation (R&I) fund, are working with academia and other stakeholders to ensure that R&I alongside S&T play active roles in realising the objectives of the MiR policy and the national development goals of Rwanda. Stakeholders maintained that renewed efforts, exemplified by the production of new policy documents such as the National Research and Innovation Agenda by the NCST and the Proof of Concept (by MINICT), attest to the government's resolve to foster economic growth and enhance competitiveness through manufacturing.

Key insights from the manufacturing workshop are summarized below under the respective categories:

- **Made in Rwanda (MiR) Policy, Regulations and Governance**
  - The main goal of the "Made in Rwanda (MiR) Policy" is to create jobs. This is done through empowering specific sectors namely construction [infrastructure], agro-processing and light manufacturing. MiR was adopted in 2018 and is being implemented by the Ministry of Trade and Industry (MINICOM).
  - MiR has identified 7 priority areas where technologies can make the most impact. These priority areas are used as the starting points for the TNA – Agro processing, Construction materials, Light manufacturing, Horticulture, Tourism, Knowledge-based services, and Logistics and transport (GoR MIR policy, pp22-23).
  - Manufacturing processes are currently unclear in Rwanda. It is vital to map out the different manufacturing processes to help demand assessments. Technology can play a major role in this regard – matching demand with supply.
  - Improving efficiency, cutting the cost of production, and adding value to MiR products (for example, minerals) remain some of the key areas of needs where technology deployment can make significant impacts.
  - Policies and regulations for promoting local manufacturing industries is needed [MiR is cross-cutting and broad. There is need for sector-specific policies and regulations for manufacturing. Such sector-specific policies and regulations could help to ensure standards, improve certification, or improve interactions and linkages among sector actors and stakeholders].
  - The previous/current manufacturing ecosystem is fragmented with limitations on e.g., physical space resources. This calls for a need for strengthening corporate governance, as this is lacking in the ecosystem. Improvements in corporate governance will help, for example, ascertain the status of firms, how well they are

7 Republic of Rwanda, National Industrial Research and Development Agency (2018) The Made-In-Rwanda Policy Launch, Available at: https://www.nirda.gov.rw/pressroom/pressroom-detail/news/the-made-in-rwanda-policy-launch/?tx_news_pi1%5Bcontroller%5D=News&tx_news_pi1%5Baction%5D=detail&cHash=beaa9e9fd295733ecdd21a98bebc1b6a

performing, growth trajectories, and financial flows. These factors are essential for supporting firms' ability to secure bank loans and access other resources

- **Education, training, and capacity building**
  - Education and training – capacity building is needed, to help firms graduate from low tech to more sophisticated techs. Otherwise, the industrial packs will suffer.
  - Capacity building on advanced technologies is essential to improve adoption and help firms save costs, partly through improving efficiency. Capacity building should also seek to address gaps in firms/industry management.
- **Manufacturing ecosystem, R&D, and the need for technology upgrades**
  - This is the right time for Rwanda to position itself as the manufacturing hub for Africa, using technologies.
  - Yet, many firms in Rwanda are still using outdated techs (traditional machinery). Modern technologies such as AI are needed
  - Deployment of new technologies such as AI, IoT, Big Data and robotics will not only spur the creation of jobs, but it will also contribute to improvising efficiency.
  - In addition to structures and management and industrial standardization, most firms in manufacturing sector do not perform research. Firms need to have active R&D units to be more innovative. Digital technology and automation (robotics) are also key is manufacturing firms are to be competitive.
  - There is the need to improve understanding on the concept of growth and growing faster. And the role that technologies can play in the process. Without this understanding, attempt to help firms adopt techs will come across as tech/supply push and are very likely to fail or result in less than optimum outputs and outcomes.
  - Currently Rwanda imports more than it exports, resulting from low innovativeness and competitiveness.
  - Unlike High Income Countries (HICs) where universities are the main sources of technology, universities in Rwanda (such as those teaching electronics and electrical engineering, and computer science) are not focusing on R&D so that they can produce prototypes in which the industries can invest.
  - There is no need to import technologies which increase costs or work against the SDGs.
- **Standards and Quality Improvements**
  - There are currently significant challenges with standards and standardisations, which often do not meet international standards – this is essential for improving and ensuring Rwanda's competitiveness. Poor standards and standardisations (particularly in manufacturing firms in informal settings) also lead to low productivity, efficiency, growth, and impact on national development.
  - Related to standards and standardisations, is the need for Quality Management Systems (QMS)[8], which are essential for various reasons, for example, to improve traceability of manufactured products.
  - Some industries do not have structure and do not follow standards – two factors essential to embracing QMS.
- Case Studies, as examples of the role of technology in manufacturing: It is vital for Rwanda to harness and better exploit what it already has. To this end, two (2) examples were highlighted of the ways that STI can help drive economic growth (see also Section 4.3 below for related Case Studies):
  - Example 1: [Sweet] Potato used in bread production. This case can help provide the link between Manufacturing and Agriculture while reducing import of raw material for bread production. Actors involved in this sub-sector (bread production) are young people who understand the need of technology. Achieving this would require technology push from government approach.

8 A quality management system (QMS) is a structured system for recording the structure, roles, and processes that are necessary for effective quality management" (NCST, 2021, p.48) In this instance, used in the broad sense to cover technology development, deployment, appropriation, dissemination, adoption and management

- Example 2: Minicom partnership with Rwanda Stock Market to organize Business Clinics that help firms better understand and appreciate the role of corporate governance and tech in firms' growth.

- **Context**
  - Rwanda is landlocked, with high transportation costs for imports and exports. NTB increases transportation costs. Raw materials are imported, and goods need to be often by roads or air which affect the cost of locally produced material for instance if they are to be exported.
  - COVID-19 pandemic and related travel restrictions have increased transport logistics, including quality checks.
  - The issues of infrastructure such as mobile/broadband communication, road, and air transport cost across different countries in African are affecting the manufacturing sector.
  - Drawing from the experience of camera and mobile application (SMS communication) systems being used by the traffic police in Kigali, technologies such as AI, IoT – which underpin the efficiency in the public sector (traffic control systems) are essential in manufacturing. These technologies (focusing on 4 pillars: people, software, hardware, and connectivity) could be deployed to improve efficiency in the private sector and in manufacturing.

4.2.2 Technology needs, barriers, challenges - Manufacturing sector

Technologies needed in the manufacturing sector will serve among others, to:

1. Support optimization and improve resource efficiency and reduce waste (for example, 3D/4D) and e.g. (food) processing, for example, technologies for automation.
2. Cut/reduce the cost of production for example, via transportation or reduce cost of energy by helping firms transition to the use of solar.
3. Upgrade and Promote MiR products. And upgrade firms in the manufacturing sector.
4. Add value to products, for instance, in the agriculture sector (for example, coffee which returns to Rwanda 10x or 20x better quality), fashion industry, mining (for instance, minerals exported out of Rwanda).
5. Increase awareness of the role of technologies in improving firm growth and economic development.
6. Access demand (and hence, match demand with production/manufacturing).
7. Improve logistics and reduce transport and transaction costs- particularly in the current times of COVID-19 pandemic.
8. Traceability of product throughout all steps of value chain, that is, (farm-industry-market value chain).
9. Low-cost green energy (such as solar energy) for efficiency across the value chain (from firm to factory).
10. New technologies such as AI, IoT to improve the efficiency in manufacturing.
11. [Big] Data for predictability.

Table 9 provides a summary of technology needs in the Manufacturing sector based on data gather from stakeholders' workshops and interviews, complemented with secondary data.

Annex 5 provides insights on the intersections between Manufacturing Sector needs outlined above in Table 9 and technology solutions (see Section 5).

4.2.3 Enabling environment and opportunities for transformation

The evaluation of the enabling environment aimed to identify barriers and challenges that hinder the deployment, diffusion, transfer, or acquisition of technologies in Rwanda. In this respect, the findings from the workshop revealed that factors that hinder the deployment, adoption and utilization, diffusion, transfer, acquisition of technologies in Rwanda include:

1. Low levels of IT literacy, capabilities, and skills, contributing to the low understanding of technologies and their roles in business growth and economic development. One Workshop participant stated that "Rwandans still do not fully understand technologies".

Table 9: Summary of Technology needs, barriers, and challenges in Manufacturing

Focus area	Technology needs: Technologies for…	Barriers and challenges with respect to specific needs	Possible technology solutions and opportunities for transformation
Productivity increase	Support optimization, improve resource efficiency and savings, and reduce waste	Gaps in technology[1], infrastructure, capabilities, governance, standards, awareness of the role of techs, finance, and policy support	3D, 4D, Automation, AI, IoT, Big Data
Cost of production	Reducing the cost of production e.g., by lowering labour or inputs (e.g., electricity) cost	Inability to effectively develop, appropriate or deploy techs such as solar, robotics and AI	Robotics (a bit futuristic for Rwanda) but can help in the reduction of production costs, increase of productivity
Value addition, industrialis-ation, competitive-ness, upgrade and promote MiR products	Value addition to raw materials, boosting competitive industrial sector. For example, 1) value addition to minerals, 2) spare parts to machines, 3) standardisation	Difficulties with M/SMEs ability to process raw materials into semi-finished products. And supply semi-finished products to larger firms and industries	Techs for storage, reducing post-harvest losses, sun/air drying, tanning, refrigeration, transportation
Processing, packaging, and transportation	In animal (livestock) farming, for example, the focus on livestock for milk purposes means that there is high demand in milk processing, storage, transportation, and related activities	In textiles operations, for example, technologies can help in tanning of hides and skins to avoid or reduce the use of chemicals, resulting in less environmental degradation.	With the focus now on milk producing cows; techs e.g., for processing of milk is priority
Information sharing and communica-tions	Increasing awareness of technologies	Deeper analyses – which looks at the value chain – such as structural issues, market access, access to raw materials, etc	Technologies for value-addition to agricultural products and including processing, packaging, branding, marketing, transportation, and logistics
standardis-ation, traceability of manufactured products, and quality control	Ensuring standards in products, e-traceability of products, goods, and services; certifications, and quality control	Significant challenges with standards of manufactured goods, which often do not meet international standards. This reduces progress of the MiR by hindering competitiveness	Example: Quality Management Systems (QMS), which are essential for various reasons, e.g. to improve quality and traceability of manufactured products
Infrastructure, logistics and transport	Ensuring standards in products, e-traceability of agriculture and food systems products, goods, and services; certifications, and quality control	Ability to ensure accurate data and information on the origins of products (e-traceability of agriculture and food), adherence to standards, certifications, and quality control by producers	Standards, such as ISO's and others applicable to foods and drugs
Capabilities and skills	Capabilities and skills are needed to understand, absorb, and utilise modern/ advanced techs	Skills gap remains a major hinderance in the manufacturing sector	Similar to agriculture, context-specific technologies, alongside appropriate frameworks, and policies, must underpin capacity strengthening at low- and high-tech levels. Platform technologies deployed must be multi-sectoral

1 In this instance, used in the broad sense to cover technology development, deployment, appropriation, dissemination, adoption and management

2. Questions were raised around the percentage of Rwandan farmers who own smartphones and are able to effectively utilize the smart features. For this population segment, deepening understanding on other technologies (e.g., voice over data) that may be utilized to deliver information and other essential services is vital. This calls for market segmentation.
3. Policies and regulations: In this sense, there is the need to review polices and regulations to help support the implementation of STI policies
4. Infrastructure, which although has improved, requires further enhancements to support the demand in technologies, digitalization, and the transformation agenda of Rwanda
5. Access to technology: some farmers do not have smartphones. For Rwandans in this group, there is need to consider other routes for them to access technologies.
6. Funding: as shown in Sections 4 to 6 of this report, funding – an important and re-occurring theme – alongside capabilities is central to innovation and the implementation of the TNA report. Although domestic funding for STI and R&D in Rwanda has "received a substantive boost with the establishment of the Rwanda Innovation Fund and the launch of the National Research and Innovation Fund" (NCST, 2021, p.73), the level of funding remains considerably low compared to what is needed to achieve the STI objectives of the country. And, for example, reach the 1% of GERD recommended by the African Union. Nevertheless, progress is being made on various fronts. For example, recent evidence reveals, that institutions across Government, Higher education, Not-for-profit and Business sectors, in Rwanda continue to commit capital for investments in technologies. This is indeed a positive and welcome trend. Nevertheless, investments in ICT imports remain low when compared to international standards (NCST, 2021). While technology imports are useful and relevant, this report, however, advocates for increase in domestic technology development, as opposed to higher levels of imports. To achieve this, finance, capabilities, and appropriate policies and regulatory frameworks are essential.
7. Common challenges for both TNA sectors: capabilities, increase in R&I investment, funding, and policy and regulatory support.

Figure 8: Example of URWIBUTSO Enterprise products. *Source: Sasha (2014)*

Despite these challenges, the environment for technology in Rwanda is favorable, with some policies and regulations in place[9]. In addition, there is strong willingness among the ecosystem actors for STI to help realize the SDGs. Section 4.3 below provides two case studies that help demonstrate how technology and innovation is being harnessed in agriculture and manufacturing sectors in ways that help advance Rwanda development aspirations and the SDGs.

Figure 9: URWIBUTSO Enterprise bottling plant. *Source: Adelphi (2015)*

9 Including the ICT4RAg, https://imbaraga.org/IMG/pdf/ict4rag_strategic_plan_2016-2020_final__final__3_.pdf; and Made in Rwanda policy, designed to help boost manufacturing

4.3 Case Study: URWIBUTSO-Sina Gerard, a Medium Technology Social Enterprise

URWIBUTSO-Sina Gerard, a Medium Technology Social Enterprise

URWIBUTSO Enterprise is a food processing company created in 1983 by an innovator and social entrepreneur named Mr. Sina Gerard. The company is headquartering in Nyirangarama, Rulindo district, in the Northern Province of Rwanda, roughly at the central point of the main road connecting Kigali (Rwanda's capital city) and Musanze (main city of Northern Province). URWIBUTSO Enterprise has registered exceptional expansion – in size (see below) and quality – over the last two decades and more and this success has in part been largely attributed to the innovative and creative capabilities of its founder and owner, Mr. Sina Gerard. Starting with only one product, donut, named "Urwibutso", the business has expanded gaining the capacity to produce a wide range of products (see Fig 8), including the most famous hot oil chili "Akabanga" on the local and (East Africa) regional market (Sasha, 2014), with around 8-10% of the products being exported (some of them are exported to Europe) Adelphi (2015).

According to Sasha (2014) and Adelphi (2015), URWIBUTSO Enterprise, which started with only one staff in 1983, currently employs more than 400 people, including five (5) trained agronomists, while contracting 3,000 farmers from the local community – a vital social innovation project. Part of the agronomists' responsibilities include providing "technical assistance on effective farming techniques" to the 3000 farmers and ensuring quality and standard of processes. According to Adelphi (2015) and Iwacuonline.com the company is ISO 9001:2000 and ISO 22000:2005 certified since 2007 for social responsibility, but it is yet to receive a "fair trade or organic certification".

The company uses machine-supported processes in the category of Medium Technology level as Adelphi (2015) suggests (see Figure 9). On the local market, the supply chain is largely characterized by a complete circle of flow of products from farms to table via the company's stores in different parts of the country. In its nature of social enterprise, URWIBUTSO has been investing in the local community, highlighting, again, a vibrant social innovation component to business. For instance, 800 children of the 3000 contracted farmers are enjoying their education in one primary school and one secondary school both created and run by URWIBUTSO Enterprise. The social and economic influence of URWIBUTSO Enterprise to the Nyirangarama community, including tourism, may in part claim to be an example of an inclusive and social innovation ecosystem in a local setting. This inclusive and social innovation ecosystem is essential to addressing the SDGs.

Aside from consistent success of URWIBUTSO Enterprise, the company may leverage technology to further boost its productivity and quality. For instance, the assessment conducted by Adelphi (2015) revealed that the company was lacking cooling storage system, hampering its ability to store seasonally products. Additionally, the company was experiencing the technical issues with its production line (bottling plant) presenting a setback to its production capacity.

CHAPTER 5
Assessment of Technology Needs and Factsheets

5.1 Results of Technology Needs Assessment

As discussed in Section 1.3, the methodology of this Science, Technology, and Innovation (STI) Review and Technology Needs Assessment (TNA) for Rwanda, undertaken by UN Technology Bank for the least developed countries (Technology Bank), included the organisation of three workshops, in partnership with the Ministry of ICT (MINICT), Rwanda. A summary of the highlights and key messages from the workshops were presented in the findings, Section 4 above. This section builds on the needs assessments presented in Section 4 above (as summarised in Tables 8 and 9). And provides further insights from the stakeholders' consultation, the criteria for selecting the technologies presented and a Factsheets section that outline the selected technologies that are captured in the STI review and TNA report.

To reiterate, the data collection for the STI Review and TNA involved Focused Group Discussions (FDG), meetings and three (3) separate workshops with 15-20 participants in each workshop.

- Workshop 1 and FGDs: Key technology and innovation actors and stakeholders from sectors outlined in Section 2.3 above: Energy, Agriculture, Health, manufacturing, ICT and Innovation, Environment and Cross-cutting themes. 10-15 participants in total, with about 2-3 participants representing each sector
- Workshop 2 and FGDs: Stakeholders from Agriculture sector
- Workshop 3 and FGDs: Stakeholders from Manufacturing sector
- Expert interviews: The workshops findings were complimented with insights from targeted expert interviews, conducted in the months of July and August 2021.
- Workshop 4 and FGDs: Validation meeting with broad STI and development stakeholders from Rwanda and beyond

Results of the TNA are discussed in the sections below, starting with the categories of technologies that emerged from the data.

5.2 Categories of technologies that emerged from the data

A key finding from the workshops was the consensus among participants that technologies are essential to progress in Rwanda's development and transformation and realizing the SDGs. Based on the insights from the sectoral workshops, three categories of technologies were identified.

1. **Technologies considered to be in the Affordable and Inclusive ("low-tech") range.** Technologies in this category were deemed necessary for supporting initiatives and actors that, although vital to economic development and transformation, are currently at the grassroots innovation levels. The majority of initiatives and actors in this group are characterized, broadly, as predominantly rural, and small farmers or SMEs, women, with less resources (for example finance or access to finance and land), subsistence farmers or small industries and manufacturers, and with considerably lower levels of IT literacy, capabilities, and skills. The main technology identified to be in the group is mobile (including smart) phones, internet, and online platforms.

   It was noted that for example the government sends out meteorology info via SMSs. However, due to lack of mobile/smart phones ownership by some citizens and gaps in capabilities and skills (including poor digital/IT literacy), many farmers in the rural areas are not able to access and benefit from such vital resource that could potentially improve their productivity and profit margins. Another key area of smart/phone use identified relates to mobile money and money transfer. Mobiles in this sense is vital to ensuring inclusion of rural, excluded, and marginalized communities, thereby, improving the prospects of achieving the SDGs.

2. **Online systems and platform technologies** for enhancing coordination within the value chains, communications, connectivity, and

engagements among actors and stakeholders. The main technologies identified to be in the group are internet and online platforms designed to:

a. Enable stakeholder management,

b. Match demand and supply, for instance, helping connect farmers (as suppliers) to buyers (demand), share information with knowledge producers (e.g., universities and researchers and research networks) or support capacity building

c. Help track the movements of goods, farm produce or manufactured products from producers, through intermediaries, to buyers.

Internet and online platforms were considered to be more difficult to be developed, deployed, and utilized by actors in this group. Rather, the focus is on low, basic, and simple techs for example to enable SMS communications that supports farmers who want to upscale from subsistent agriculture and food systems.

3. **Technologies considered to be in the "high-tech" range, that is, advanced technologies.** Technologies in this category serve to support initiatives and actors that are more advanced and with the requisite capabilities and skills, funding and/or access to resources including finance, land, equipment, and markets. Examples include Artificial Intelligence (AI), Internet of Things (IoT), Drones, 3D/4D, Blockchain technologies, robotics, and automation. For example, AI for improving irrigation, precision farming, prediction, analyses (of market, customer, or crop health).

4. **Technologies for e-businesses**, mostly new business start-ups, spin-offs, and SMEs. This fourth and cross-cutting group relates to technologies for new businesses – start-ups, spin-offs and SMEs in agriculture or manufacturing. Some of the gaps in knowledge include better understanding of the technology needs and the challenges related to value chain issues encountered by e-business actors.

Annexes 4 and 5 summarises some of the key insights on the intersections between Agriculture and Manufacturing Sector needs outlined in Tables 8 and 9, and technology solutions discussed in the categories above.

Based on the findings discussed above, the next section presents Factsheets of five technologies: two for Agriculture sector, two for Manufacturing sector, and one cross-cutting group, referred to as platform technology, which applies to both agriculture and manufacturing.

5.3 Sectoral Technology Analysis: Factsheets of Priority Technologies

The purpose of the factsheets in this section is to create a succinct document that synthesizes essential information for each priority technology. The factsheets help to communicate key points and issues on the technologies while ensuring that the information is presented in such a manner that both technical and non-technical experts alike can understand it. As emphasized in preceding sections, transformation – in terms of achieving sustainable economic prosperity while also addressing social (for example, inequality and exclusion) and environmental challenges (including climate change and biodiversity loss) – is central to this STI review and TNA. And forms the basis for the selection of the technologies in the factsheets discussed in this section. The objective in this section is not to offer exhaustive discussions on individual technologies, but rather to provide key information that forms the basis for the development of implementable policies, regulations and detailed programmes and projects.

A note on the Ranking of identified technologies in the factsheets

As the identified priority technologies did not constitute an extensive list, rather four categories with three technologies selected for each category; it was not necessary to follow complex methodologies such as multi-criteria decision analysis (MCDA) in ranking the technologies in order of priority. Therefore, ranking was based on insights from the workshops,

complemented by the interviews, and corroborated by stakeholders during the validation workshop. This approach ensures that the ranking follows a grassroots process that is inclusive and improves ownership by stakeholders. Buy-in and ownership by stakeholders is essential to improving the prospects for implementation.

5.3.1 Factsheet 1: Affordable and Inclusive ("Low-tech") Technologies for Agriculture

The main issue for farmers is production and challenges related to increasing productivity. Other challenges identified include information, data, and knowledge sharing, and capabilities. A recent study found that 46% of Rwandan households suffer from insufficient food while 42% of households benefitted from improved livestock feeding at small costs to the environment[1]. Innovations in the form of incremental changes or improvements in agriculture with potentials for enhancing productivity could be, for example, in the use of greenhouses to improve the prospects of achieving "climate smart", more efficient application of fertilizers and pesticides or better utilisation of information, data, and knowledge by famers. Innovative farming techniques – that help reduce the use of inorganic fertilizers and improve soil quality or the diversification and rotation of crops – can help improve productivity. Three affordable technologies in this regard are provided below.

- **Technologies** – Greenhouses, Biodigesters, Mobile phones
- **Technologies explained** (see Table 10 for further details)
- **Greenhousesl**[2]:
  a. Can be operated at affordable at small or large scale, low/high-tech
  b. The enclosed environment means that farm inputs – temperature, water, fertilizers, etc. – can be better controlled and optimised to help increase productivity e.g., by improving resources use efficiency and reducing costs
  c. Although affordable ("low-tech") greenhouse agriculture is the focus in this Factsheet, there are many examples of "high-tech greenhouse technology3 applications across the world that Rwanda can learn from and adopt.
  d. Greenhouse is a key infrastructure for agriculture in Rwanda. However, it requires funding (MINAGRI, 2018). The Government of Rwanda, as outlined in the Strategic Plan for Agriculture Transformation "supports the introduction of modern production infrastructure such as greenhouses for vegetables and flowers and hydroponics under PPP arrangements in specific sites to showcase their potential. The aim is to attract more private sector investment in these areas in future" (MINAGRI, 2018, p.49).
  e. Greenhouses are vital to Rwanda's ambition towards improving food security, realising the goal of climate smart agriculture, and achieving the SDGs4.
- **Biodigesters:**
  a. Rwanda's agriculture sector face severe challenges, some of which result from increasing rates environmental degradation, due to the high use of inorganic fertilisers and chemicals. There is likelihood that the challenge of environmental degradation will be exacerbated by the increase in population5. These high rates of environmental degradation, a major barrier to achieving the SDGs, contribute to the declining productivity.

1 Paul, B.K., R. Frelat, C. Birnholz, C. Ebong, A. Gahigi, J.C.J. Groot, M. Herrero, D.M. Kagabo, A. Notenbaert, B. Vanlauwe, M.T. van Wijk (2018). Agricultural intensification scenarios, household food availability and greenhouse gas emissions in Rwanda: Ex-ante impacts and trade-offs, Agricultural Systems, 163, 16-26, https://doi.org/10.1016/j.agsy.2017.02.007.

2 Although placed in the affordable technologies category, there are indications that greenhouses may be considerably expensive in Rwanda. This is noted. However, if done in partnerships or within cooperatives, the costs is still not considered to be prohibitive as these examples indicate: Why greenhouse farming is the future of young farmers, July 2019, https://www.newtimes.co.rw/business/why-greenhouse-farming-future-young-farmers

3 Forbes (2020) High-Tech Greenhouses could be the Future of Agriculture, Available at: https://www.forbes.com/sites/jordanstrickler/2020/08/28/high-tech-greenhouses-could-be-the-future-of-agriculture/?sh=41df2553380f

4 World Bank (2020). Rwanda: Food Smart Country Diagnostic. World Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/34523

5 Paul et al., 2018

Box 3: Technology and Information Access in Agriculture

Effective application of ICT can help accelerate productivity and efficiency in the sector and is key to reaching people at a large scale. ICT can support agricultural growth by providing appropriate, timely information to farmers and other stakeholders. Core services where ICT can make an impact include development of a common user interface and a repository for farmer and farm information; increasing farmers' skills and knowledge through online learning; contributing to job creation among youth in agriculture and peripheral services; improving access to agricultural information, knowledge, and markets; and expanding access to, and uptake of, rural and agricultural financial services.

Source: Strategic Plan for Agriculture Transformation (p.28)

b. A viable pathway is climate smart agriculture, aiming at the triple win of improving food security and climate change adaptation, while contributing to mitigation if possible. The Government of Rwanda has initiated ambitious policies and programs aiming at low emission agricultural development.

c. Biodigesters can help reduce the use of inorganic fertilizer, and improved seeds. In the livestock subsector, zero-grazing and improved livestock feeding are encouraged,

d. Can help farmers address the challenge of soil degradation resulting for high use rates or inorganic fertilizers thereby. And achieve a balance between organic manure and inorganic fertilizers – from composting and biodigesters

e. In the SDGs era of high environmental focus, biodigesters can contribute to efforts in realising climate-friendly agriculture.

- **Mobile phones**

a. As discussed in Section 4 above, mobile phones are useful for farmers low income and rural farmers. This technology, which is available and accessible, can help improve communications agricultural stakeholders and reduce the information, data, and knowledge gaps in the ecosystem. Examples include up-to-date access of weather data, price, and market information.

b. Box 3 helps illustrate the role of technology in improving information access in Agriculture while highlighting other vital aspects such as the target audience (rural farmers especially), the main benefits, and areas of possible application.

A note. Important feedback from stakeholders relate to the development of an affordable technology in the form of a specialised small machinery for highlands. Rwanda is made up of hills and mountains, hence difficulties in the use of conventional big machinery in farming. Farmers in highlands, especially in north and west, use basic farm tools, bare hands, and hoes in their farming activities. Therefore, machinery adapted to highlands would be essential to increasing productivity.

- **Barriers, enabling environment and opportunities for transformation**

  The key barriers and hindrances, that also have implications on the ability of these technologies to foster transformation, relate to

  a. Finance – for example, ability to secure formal loans remains a major challenge for farmers. Finance is essential for setting up greenhouses (see Table 10).

  b. Capabilities – as outlined in Table 8.

  c. Policy support and enabling regulatory frameworks.

- **Technology ranking** in order of priority:

  a. Greenhouses

  b. Biodigesters

  c. Mobile phones

Table 10 presents a summary of the key issues to be considered in implementing the three inclusive technologies for agriculture that are discussed under this factsheet.

Table 10: Implementing Affordable and Inclusive Technologies for Agriculture

	Technologies		
Key issues	**Greenhouses**	**Biodigesters**	**Mobile Phones**
Main features and objectives	Farming in a more controlled environment	A system that helps break up organic and inorganic materials	Key device for information and communication
Status of the technology in Rwanda	Outlined as focus area to support innovation and extension (MINAGRI, 2018)	As FAO (2021) highlights, it is important, needs to be better exploited	Cellular mobile subscription (per 100) of 82% and 26% using internet[6]
Existing institutions with capacities to develop and transfer this technology	MINAGRI, cooperatives, some private sector, grassroots innovators, and entrepreneurs	Between 2007 and 2009 Rwanda installed many biogas plants. Capacities: Kigali Inst. of Sc., Tech., and Mgt. (KIST)[7], academia...	Various MNOs, small scale mobile actors, innovators, entrepreneurs, and government actors including MINICT
Will new capabilities be required? If yes, what will it be?	Yes – funding, set up, operation. However, some capabilities already exist within the agriculture sector	Some capabilities exist e.g., in KIST; additional capabilities are essential for e.g., transfer of this technology	No, the preference is to harness existing capabilities and skills; and if need be, strengthen such capabilities
How will this technology address the needs of Rwandans?	It can increase "harvest up to 500 tonnes per hectare, or 100 tonnes on 0.2 hectare, against about six tonnes produced (on 0.2 hectare)[8]	Can help reduce the use of inorganic fertilizers and contribute to sustainable energy source for electricity (biogas), and heating	Improving access to relevant data and information e.g., on climate risks[9], on productivity enhancements, farming methods, etc
Main beneficiaries	Farmers, agriculture sector ecosystem actors, Rwanda	Farmers, agriculture ecosystem actors, Rwanda's SDGs	Rwandans in general, farmers, agriculture actors
Approximate number of beneficiaries	More than 4 million Rwandans involved in agriculture	4 million Rwandan farmers and other agriculture actors	Rwandans in general, 11+ million, farmers, and others
Main benefits of implementing the technology	1. Increased productivity 2. Higher incomes and improved well-being 3. Addressing the SDGs 1-17	1. Lower production cost; higher incomes 2. Increased productivity 3. Addressing the SDGs 1-17	1. Productivity and knowledge increase 2. Incomes improved well-being 3. Enhanced communication
Gender dimension of the technology[10]	Can significantly enhance inclusion for women and youths	Can be operated by women and youths, fostering inclusion	High potentials for improving gender inclusion and access
Environmental dimension of the technology	If well managed, can reduce GHGs from farming[11]	Can help address challenges on energy and fertilizer use	Use of mobile phone has low impacts on the environment
Main disadvantages of implementing the technology	1. Requires time, capabilities and skills for monitoring and management 2. Set up and maintenance costs 3. Others: pollination, maintaining regular supplies of nursery plans, aesthetics	1. Initial set up and maintenance costs 2. Capabilities and skills gaps 3. Raw materials – the challenge of maintaining a regular and sustainable supply of inputs	1. Smartphone are expensive, although the low-end phones may be affordable 2. High carbon impact during production and disposal/ recycling 3. Capabilities and skills gap, especially for rural citizens
Implementation cost estimate - Low, medium, or high[12]	Low to medium[13]	Low to medium	Low to medium

6 World Bank, Country Profile – Rwanda, Available at: https://databank.worldbank.org/views/reports/reportwidget.aspx?Report_Name=CountryProfile&Id=b450fd57&tbar=y&dd=y&inf=n&zm=n&country=RWA, accessed 7 July 2021

7 https://ashden.org/winners/kist/

8 Rwanda to spend over Rwf 8bn on greenhouses, hydroponics, https://www.newtimes.co.rw/article/162479/News/rwanda-to-spend-over-rwf8bn-on-greenhouses-hydroponics

9 FAO (2018) In-house collaboration to increase access to market prices and climate risk information for small potato farmers in Rwanda through ICTs, Available at: http://www.fao.org/e-agriculture/news/house-collaboration-increase-access-market-prices-and-climate-risk-information-small-potato

10 The technologies selected in this group have gender dimension as the central focus. Some evidence indicate that cooperatives in Rwanda have more women than men. With about 8000 cooperatives listed in the Rwanda as of 2018 (see: https://link.springer.com/article/10.1007/s12571-019-00944-9); there is potential for significant impacts from technologies application with opportunities for transformative change

11 Paul et al (2018), https://www.sciencedirect.com/science/article/pii/S0308521X17301749

12 Cost estimates to be discussed and agreed with stakeholders at the validation workshop

13 "For instance, a high-tech greenhouse to cover an agricultural area equivalent to 800 square metres costs about Rwf40 million, while it can cost Rwf10 million for the low-tech option", See also: MINAGRI (2018) – Strategic Plan for Agriculture Transformation 2018-24, for more on this

5.3.2 Factsheet 2: Advanced ("High-tech") Technologies or Agriculture

Large scale (or "big")[14] farmers in Rwanda are not same as big farmers in the West. In Rwanda, large scale farmers might have big land, however, their ability to absorb technologies (that is, absorptive capacity) is comparatively low. The three technologies discussed in this section – drones, AI, and robotics – can complement each other, hence the grouping. For instance, drones, which are robotics tools, utilise AI.

- **Technologies – Drones, AI and IoT, Robotics[15]**
- **Technologies explained**

  Drones:

  Drone use in agriculture has grown in recent years, globally, particularly driven by advances in the technology and lower costs, demand for increased productivity in farming and precision agriculture, and the move towards sustainability transitions.

  For example, smart irrigation using drones contributes to achieving the SDGs via sustainable use and management of water in agricultural. Drones are also used in livestock herding, farm security, monitoring of crops and livestock, fertilizer prescriptions and applications, mapping farm fields and conducting livestock counts. In addition, drones have helped to reduce travel to and from farm sites by e.g., live-streaming high-resolution imagery and footages to where they are processed by farmers or research teams. Furthermore, drones are being deployed in what some refer to as "decision agronomy", the use of drone tools to make and implement timely and better-informed decisions, for example on seed yields and quality. In Rwanda's context,

  a. Drone technology is already available and utilised in the country, therefore could improve the prospects for easier access, development, adoption, and transfer.

  b. Can support precision / smart agriculture, for example, in aspects that include smart irrigation and fertiliser application, soil, water and land management, or solar energy adoption.

  Artificial Intelligence (AI):

  AI, often deployed as automated robotic systems, are revolutionising agriculture – from fostering advancements in the optimisation of irrigation and use in weed controls, to crop monitoring and application of pesticides and herbicides. In Rwanda, AI applications can help

  a. Can help improve farmer productivity through application in areas such as in the identification of plants that require irrigation or fertilization.

  b. Can provide farmers with real-time data analytics, information, and insights from their fields, on climate crop or conditions, animal health, soil, and other conditions that have bearing on productivity.

  c. May help increase efficiencies, crop yields, and food production by minimising the use of resources.

  d. IoT-enabled Agricultural (IoTAg) technologies, useful for real-time monitoring, sensors, and smart farming, is one of the fastest growing areas of Agricultural Technologies (AgTechs).

  Robotics:

  a. Vital for automation and precision agriculture, robotics can help improve farmers productivity through application in areas such as processing and packaging, standardisation, quality control and traceability.

  b. Robots are well suited for tackle labour-intensive and repetitive tasks for example in the coffee and tea, textile operations or fruits and vegetables harvesting, which involves physically demanding activities.

14 1-5 hactares of land ownership is considered a middle farmer while greater than 5ha is a big farmer

15 It is important to note that the Rwandan Government still categorises AI, IoT, Machine Learning, Drones, Robotics, 3D Printing, and GPS as Emerging Technologies (NCST, 2021, p.51). This is in line with the findings of this report, where the term "growing" has been applied to the some of these technologies (see Section 5), indicated that the technologies have already "emerged" but are now in the growth stage

Table 11: Implementing Advanced Technologies for Agriculture

Technologies			
Key issues	**Drones**	**AI**	**Robotics**
Main features and objectives	Drones are Unmanned aerial Vehicle (UAV)	Artificial intelligence, machine learning	STI, ICT, computing, and engineering
Status of the technology in Rwanda	An active and growing field, deployed extensively during Covid-19 interventions	Still in the early stages of development, application, and tech transfer	A growing field with high potentials for economic transformation
Institutions with capacities to develop and transfer this technology	Zipline, mostly; but other institutions are emerging. Govt. actors include Rwanda's national aviation authority, Rwanda's Civil Aviation Authority (CAA)	In the addition to e.g., Zipline and CAA, others include Centre for 4IR (C4IR), AIMS and CMU-Africa, Shaka AI Ltd and SOLVIT Africa, UR – Centres of Excellence in AI, RDB[16]	In the addition to the specific institutions listed under Drones and AI; sectors with capabilities, and already deploying Robotics include agriculture, health, and manufacturing
Will new capabilities be required? If yes, what will they be?	Yes. Capacities related to the design and domestic manufacturing, software, upgrades and maintenance and mgt.	Yes. AI and Machine Learning are advanced technologies, requiring advanced skills	Yes. Like Drones and AI, requires intermediate to advanced capabilities and skills
How will this technology address the needs of Rwandans?	Will drastically improve agricultural productivity, farmers primary concern	Essential to achieving the goal of increased farm productivity	Useful in harvesting, processing, or helping farmer access crops
Main beneficiaries	Rwandan farmers, agriculture, and allied sectors	Agriculture and allied sectors such as manufacturing, education, and health	Agriculture, allied sectors, and the entire economy
Approximate number of beneficiaries	Primary beneficiaries, agriculture sector; secondary beneficiaries, entire economy	The entire Rwandan, economy – from agriculture to manufacturing, health and education	Beneficiaries: Primary - production and manufacturing sectors; Secondary - entire economy
Main benefits of implementing the technology	1. Increased productivity 2. Potentials for lowering production cost; higher incomes 3. Sustainability transitions and the SDGs	1. Support the move to automation and mechanisation 2. Potentials for efficiency gains 3. Increased optimisation and productivity gains	1. Support the move to automation and mechanisation 2. Potentials for efficiency gains 3. Increased optimisation and productivity gains
Gender dimension of the technology	As in STEM in general, diversity in the drone field remains low with women still underrepresented	Gender divides persist, especially with respect to the more technical aspects of AI-related roles and functions	Gender divides persist, but can be addressed if the right capacities are strengthened
Environmental dimension of the technology	Can be a major tool in addressing environmental degradation	Like Drones, can help useful in stemming environmental degradation	Similar to mobile phone has low impacts on the environment during use
Main disadvantages of implementing the technology	1. Cost – purchase, maintenance etc 2. Capabilities and skills to design, develop, operate, and manage 3. Policies, laws, and regulations[17]	1. Initial set up and maintenance costs 2. Capabilities and skills gaps 3. Raw materials – the challenge of maintaining a regular and sustainable supply of inputs	1. Smartphone are expensive, although the low-end phones may be affordable 2. High carbon impact during production and disposal/ recycling 3. Capabilities and skills gap, especially for rural citizens
Implementation cost estimate	Medium to high	Medium to high	Medium to high

16 Republic of Rwanda, Rwanda Development Board (2020) The Government of Rwanda Announces the Establishment of a Center of Excellence in the Areas of Digitalization and AI, Available at: https://rdb.rw/the-government-of-rwanda-announces-the-establishment-of-a-center-of-excellence-in-the-areas-of-digitalization-and-ai/

17 https://uavcoach.com/drone-laws-in-rwanda/

- **Barriers, enabling environment and opportunities for transformation**

  The key barriers and hindrances, that also have implications on the ability of these technologies to foster transformation, relate to

  a. Infrastructure

  - Electricity, which remains high and, in some instances, prohibitive
  - Internet and broadband, also data – all of which are essential for the advanced technologies in this group

  b. Capabilities – in multiple dimensions, some of which are outlined in Tables 8 & 9

  Technology ranking in order of priority:

  a. Drones

  b. AI (and ML) and IoT

  c. Robotics

Table 11 presents a summary of the key issues to be considered in implementing the three inclusive technologies for agriculture that are discussed under this factsheet.

5.3.3 Factsheet 3: Platform Technologies for Agriculture and Manufacturing

Farmers are already organised in cooperatives and federations, enabled by some form of platforms[18]. For example, large scale farmers in Rwanda use platforms such as Alibaba, where they have registries for their produces. However, this is only one dimension of platforms. Main issues for farmers, especially, small-scale farmers, is how to improve productivity and enhance communications among the ecosystems. The other aspects that are of importance and where significant gaps exist relate to platforms for 1) farmers to better communicate and interact among themselves, 2) obtain and share vital market (e.g. pricing), data on demand and supply in relation to goods and services, information technologies and innovations, knowledge about new and more modern farming practices, and finance opportunities, 3) and connect actors and stakeholders, and STI between lot-tech and high-tech segments of the NSI. As a result, platform technologies in this regard are a special group as they apply to both TNA priority sectors – Agriculture and Manufacturing, and other sectors not covered in this report.

- **Technologies – Pricing, Finance, Learning and Capacity Development**
- **Technologies explained**
  - Pricing system platform. A platform to help farmers and buyers negotiate price. This should be a mobile-based platform, that can be managed by farmers' Federation. The unit of analysis for the platform(s) will need to be determined. For example, may be based on crop groups – e.g., cereals or vegetable growers or livestock farmers. Such platform cannot be based on value-chains as the challenges are different from individual crops. In the case of crops, the platform can be linked to sources that share info on, for example, current prices for cereals or vegetable as the case might be, fluctuations in price, demand and supply, trends, or insights on farming practices such as pruning, harvesting, fertilizer availability, costs, and application. And communicate the information to farmers e.g., when the government negotiates the price of beans with a neighbouring country, Tanzania, for instance.
  - Access to Finance Platform: As highlighted in preceding section, it is difficult for the agriculture sector (farmers) to secure loans for various reasons – including lack of a robust credit-rating system (software or platform), gaps in information, and weak financial capabilities of farmers. It will therefore help if a credit-rating system (which can be software) is developed, as a platform, to help ameliorate this challenge. The software could help banks track repayments, by e.g., using existing data and information on farmers who are already successful in other aspects of repayment, besides

18 e-Soko platform - http://www.esoko.gov.rw/esoko/Dashboard/Login.aspx?DashboardId=4&dash=true&Login=true

loans – e.g., fertilizer and other farm inputs and resources. Big Data technologies might assist in this regard.

- Other possible platforms include online (and/or offline) learning platform to facilitate peer learning, capacity development, and sharing of experience from best practices (for collaboration without compromising completion) amongst actors and stakeholders in agriculture and manufacturing sectors. Digital technologies are paramount in responding to this.

- **Barriers, enabling environment and opportunities for transformation**

  The key barriers and hindrances, that also have implications on the ability of platform technologies to foster transformation, relate to

  a. Implementation

     - The Platform Technology (or technologies) would need to be a software platform that connects market actors – demand and supply. "If we aggregate all demand in e.g., cereals or maise; suppliers, buyers, should be able to access the information to gain insights on gaps, how much more products are needed, price and other useful info" (source: interview respondent).
     - In addition, the platform(s) should be an automated system that matches demand and supply, actors, and stakeholders, low- and high-techs and other components of the NSI.
     - Furthermore, as technologies require constant improvements, the platform should operate on a PPP basis: government invests in industry actors (or private firm(s)), which purchases or develops the platform technology/ies and operates/implements it in a way that ensures continuous improvements and regular updates. It may be necessary for the government to create and manage this app/software.
     - Lastly, if the software proposed is USSD-enabled, that will increase the access to a wider base of, for example, farmers, and improve the chances of adoption and success.

  b. Financing – the development of the platform technologies, may require the government to take the lead in providing the funding, while private actors co-fund and undertake the implementation of the technologies involved.

  c. Capabilities – and skills gaps that affects the ecosystem at both low- and high-tech actors. Capabilities and skills gaps cover the entire technology value chain, including development, diffusion, absorption, acquisition, and appropriation.

- **Technology ranking in order of priority:**
  - Pricing
  - Finance
  - Learning and Capacity Development

Table 12 presents a summary of the key issues to be considered in implementing the platform technologies for agriculture and manufacturing that are discussed under this factsheet.

5.3.4 Factsheet 4: Affordable and inclusive ("Low-tech") Technologies for Manufacturing

With manufacturing recorded as the second largest contributor to Rwanda's GDP, this sector demand attention as it permeates every other sector of the economy. Effectively developed, manufacturing holds a huge potential to transformation change in that the sector can foster economic prosperity, social progress and contribute to addressing the environmental challenges. Nevertheless, efforts to address the technology gaps in manufacturing continue to prioritise high-tech solutions at the expense of (more) affordable and inclusive that are essential to realising the SDGs and Rwanda's Vision 2050. Addressing the technology needs of entrepreneurs, start-ups and M/SMEs in Rwanda can foster employment generation, enhance inclusion (or especially women, youths, and marginalised population segments), and contribute to reduction in inequality. An important fact to note is that advanced manufacturing technologies are becoming more affordable by the day. This fact informs, in part, the inclusion of robotics and 3D in this category. Robotics is discussed below; while 3D is reserved for Factsheet 5 – as it can serve as affordable/inclusive or advanced technology, depending on the level of deployment.

Table 12: Implementing Platform Technologies for Agriculture and Manufacturing

Technologies			
Key issues	**Pricing**	**Finance**	**Learning and Capacity Development**
Main features and objectives	Product and marketing pricing	Financial services, credit checking, loans, etc	Capacity building and strengthening, training
Status of the technology in Rwanda	Need to be developed and tailored to context and specific needs	Financial systems exist but they may require re/ alignments with SDGs	Capacity developments exist but they may require reconfiguration
Existing institutions with capacities to develop and transfer this technology	Universities, research institutes and centres, Ministry of Finance, private sector actors	Universities, research institutes and centres, Ministry of Finance, private sector actors	Universities in particular, but other actors exist in relevant ecosystems
Will new capabilities be required? If yes, what will they be?	No, on the part of actors to develop the platform(s); but, yes, on the part of, some, users of the platform(s)	No, on the part of actors to develop the platform(s); but, yes, on the part of, some, users of the platform(s)	Yes, on the part of platform(s) developers. It may be necessary to complement their capabilities
How will this technology address the needs of Rwandans?	Relevant to Rwandans in sectors concerned with production of goods and services	Relevant to Rwandans in sectors concerned with production of goods and services	Capacity strengthening is relevant to all Rwandans to foster economic growth
Main beneficiaries	Rwanda's broad economy, covering all sectors concerned with production of goods and services	Rwanda's broad economy: all sectors involved in the production of goods and services especially farmers with significant difficulties in securing finance and loans	Rwanda's broad economy, covering all sectors
Approximate number of beneficiaries	More than 50% of Rwandans	More than 50% of Rwandans	Enhancing digital literacy is for all Rwandans. However, needs will differ across sector and levels
Main benefits of implementing the technology	1. Access to pricing and market information and data 2. "Knowledge is power" 3. Enhancing economic growth through e.g., higher levels of export	1. Increased access to finance and ease of securing funding 2. "Knowledge is power" 3. Enhancing economic growth through e.g., higher levels of export	1. Access to price and market info and data 2. "Knowledge is power" 3. Enhance economic growth through e.g., higher levels of export
Gender dimension of the technology	High impact for women and youths, particularly disadvantaged groups	High impact for women and youths, particularly disadvantaged groups	Will contribute to achieving a range of SDGs: 1-5, 8-10, etc
Environmental dimension of the technology	Negligible negative impacts on the environment	Negligible negative impacts on the environment, but broad impacts at systems level	Improved capacities can help address the relevant SDGs e.g., 6, 7, 11, 13, 14 and 15
Main disadvantages of implementing the technology	Requires up-to-date data	1. Initial set up and maintenance costs 2. Capabilities and skills gaps 3. Raw materials – the challenge of maintaining a regular and sustainable supply of inputs	1. Smartphone are expensive, although the low-end phones may be affordable 2. High carbon impact during production and disposal/ recycling 3. Capabilities and skills gap, especially for rural citizens
Implementation cost estimate	Medium to high	Medium to high	Medium to high

- **Technologies –** Processing, Cooling, Feed production, Robotics, 3D
- **Technologies explained**
  - Processing:
    a. Farmers have low capacity for technology uptake
    b. Drying cereals and storage have been identified as critical loss points in post-harvest losses. Dryers are therefore one of the most relevant technologies that can help increase production and improve quality, enhance better post-harvest crop management. Drying technologies can help stem the high loss of vegetables (especially in the North of Rwanda).
    c. Relatedly, processing technologies e.g., potato, casava, and banana can help increase production and profit for farmers.
  - Cooling:
    a. Animal production: with the renewed focus on milk producing cows, a major challenge related to the processing and transportation of milk – from the collection centres to the dairy. This is one of the areas where the big losses occur. Proposed strategy is to secure vehicles with cooling technologies.
    b. Fruits and Vegetables: technologies for cooling and storage are equally important in increasing productivity, profitability, income, and the welfare of farmers.
  - Feed production:
    a. Feed production is an area of high demand in Rwanda. There have been efforts by stakeholders to resolve this challenge, however, stakeholders report that not much success has been recorded. A proportion of animal feeds used in Rwanda are imported from neighbouring countries, such as Uganda. However, the current geopolitical tensions and challenges of ensuring regular imports, raises concerns around sustainability and resilience of the supply chain and systems involved. Technology application in the production and processing of animal feeds could help ameliorate the gaps in the ecosystem.
  - Robotics:
    a. Robotics in this sense, do not need to be complicated or complex machines. Rather, the objective is to support small-scale manufacturers such as entrepreneurs, start-ups, and M/SMEs, in adding simplexcvii robots that handle specific repetitive tasks(s) that improve their productivity. For example, a robot that detects and sort fruits based on their sizes and packs the fruits into boxes.
- **Barriers, enabling environment and opportunities for transformation**

  The key barriers and hindrances, that also have implications on the ability of these technologies to foster transformation, relate to
  a. Finance
  b. Capabilities
  c. Infrastructure
    i. Electricity
    ii. Internet and broadband, also data
    iii. Business environment
    iv. Policy and regulations
- **Technology ranking in order of priority:**
  - Processing
  - Cooling
  - Feed production
  - Robotics (discussed above in Table 12, not included in Table 13 below)
  - 3D (applies to affordable/inclusive and advanced categories, discussed in Table 13 below)
- **Other Technologies:**
  - Computer Numerical Control (CNC) Machining and CNC Machines – computer-controlled machine tools, that are programmable and efficient in increasing the rate of automation.

Table 13: Implementing Affordable and Inclusive Technologies for Manufacturing

	Technologies			
	Key issues	Processing	Cooling	Feed Production
1.	Main features and objectives	Central to production functions, value addition	Mainly refrigeration, but other forms possible	Essential for livestock farming
2.	Status of the technology in Rwanda	Requires more efforts to e.g., reduce post-harvest losses (PHL) in agriculture and improve	Progress being made but far from the required level to help stem PHL in fruits and vegetables	Below the levels needed to support animal farming, and currently unsustainable
3.	Existing institutions with capacities to develop and transfer this technology	Multiple: private sector, academia, government. Capacities also available within the region	Multiple: private sector, academia, government. Capacities also available within the region	Multiple: private sector, academia, government. Regional capacities available
4.	Will new capabilities be required? If yes, what will they be?	Yes – equipment, funding, training, skills etc. Some of these can be obtained in-country and within the region	Yes – equipment, funding, training, skills etc. Some of these can be obtained in-country and within the region	Yes – equipment, funding, training, skills etc. Some of these can be obtained in-country and within the region
5.	How will this technology address the needs of Rwandans?	Processing is vital in 1) agriculture to stemming the high levels of PHL in fruits and vegetables - major export products for Rwanda, and 2) manufacturing, for value addition to raw materials – e.g., textiles, minerals – in readiness for export	Cooling, e.g., via refrigeration, is an important aspect of storage and processing. Therefore, can contribute to stemming PHL and improve productivity, income and wellbeing of farmers and industrialists	Ensuring availability of feedstock e.g., off-season, requires processing, and helps to address challenges related to e.g., price fluctuations, sustainability, and adverse environmental impacts
6.	Main beneficiaries	Actors and stakeholders involved in production of goods, especially perishable good in agriculture or products in the manufacturing sector that require value addition prior to sales or export	Mostly targeted at supply chain actors in Agriculture, approx. 4million	Primary beneficiaries: agriculture sector. But outputs are essential for manufacturing sector actors and stakeholders involved in the production of e.g., leather products, shoes, textiles, etc
7.	Approximate number of beneficiaries	Include supply chains actors in agriculture, manufacturing, etc – about 50% of population	Mostly targeted at supply chain actors in Agriculture, approx. 4million	Primary beneficiaries: agriculture sector. But outputs are essential for manufacturing sector e.g., leather, shoes, textiles
8.	Main benefits of implementing the technology	1. Reduced PHL 2. Increased productivity, profit, and wellbeing 3. Waste reduction; less impacts on environments	1. Improved storage, extends shelf life 2. Reduced PHL 3. Waste reduction; less impacts on environments	1. Increased availability of feeds 2. Improvements in animal farming 3. Sustainability
9.	Gender dimension of the technology	Needs better articulation; to ensure good inclusion	Needs better articulation; to ensure good inclusion	High potentials for gender inclusion
10.	Environmental dimension of the technology	Can increase impacts on environment e.g., via use of chemicals in processing	Can increase impacts on environment e.g., via emission of GHGs and high energy use	Can increase impacts on environment e.g., biodiversity loss, and higher use of land
11.	Main disadvantages of implementing the technology	1. Potentials for high impact on environment 2. Requires capabilities and skills, and finance 3. High energy costs/use	1. Potentials for high impact on environment 2. Requires capabilities and skills, and finance 3. High energy costs/use	1. Resources intensive – land, technologies, machinery, and others 2. Gaps in capabilities and skills, and finance 3. High energy costs
12.	Implementation cost estimate	Low, medium, or high depending on scale of implementation	Low, medium, or high depending on scale of implementation	Low, medium, or high depending on scale of implementation

Table 13 (Page 58) presents a summary of the key issues to be considered in implementing affordable and inclusive technologies for manufacturing that are discussed under this factsheet.

5.3.5 Factsheet 5: Advanced Technologies ("High-tech") for Manufacturing

Top manufacturing areas include in Rwanda 1) Metals, 2) Electro-mechanical – e.g., VW and 3) Pharmaceutical – drugs, methanol, and vaccines (in the planning – there are talks about setting up a vaccines manufacturing plant in Rwanda).

- **Technologies – AI, IoT (and Big Data19), Robotics, 3D**
- **Technologies explained**
  - AI:

    As global population continue to rise and the voices demanding urgent transition towards sustainability, there are more efforts by actors and stakeholders to produce foods from less lands or ensure that manufacturing results in less negative impacts on the environment. Consequently, there increased expectations – from policymakers, decision-makers, and leaders – on STI to help achieve these objectives. To this end, science and innovations, and digital technologies including AI, Big Data, IoT, Analytics, Robotics and Cloud Computing are being deployed across the world in various sectors and at different levels.

    Effectively implemented AI-powered manufacturing solutions are useful in various ways including i) predicting failures in designs, ii) handling quality assessments and improving standards (two key factors stressed by Rwanda stakeholders during the STI review and TNA), iii) automating key manufacturing processes, iv) providing vital intelligence to help manufacturers forecast demand and mange prices and inventories, and v) providing manufacturers with the knowledge and information to design and build smart operations that may help lower cost, disruptions and downtimes in manufacturing processes.

  - Robotics:

a. Although discussed under Factsheet 2 above, robotics is also applicable as advanced technologies, having been identified by stakeholders during the relevant workshops and interviews. Robotics can be complemented by AI – AI does the "soft-side" (i.e., software, programming, machine language), while robotics handles the hard (i.e., technical, and mechanical) parts. For example, in tea production, robotics can help in sorting plants and tea leaves, sifting packaging, or quality controls.

b. In advanced manufacturing, robots are used in practically every sector – from the manufacture of agricultural equipment, automobile and in vehicle production/assembly plants; to computing, telecoms and pharmaceutical industries in the manufacture of drugs.

c. Since robotics is already presented in Table 11 above, the objective is not to provide a detailed discussion in tis Factsheet, rather to highlight its application and use in advanced manufacturing. Effectively deployed, robotics can significantly contribute to achieving the objectives articulated in Rwanda's MiR policy.

19 Big Data is added in this list as a supportive technology to AI and IoT. This report does not provide detailed discussions on Big Data. For the role of Big Data in Agriculture and Manufacturing, see for example Big Data Analysis for Sustainable Agriculture on a Geospatial Cloud Framework, Front. Sustain. Food Syst., 16 July 2019, https://doi.org/10.3389/fsufs.2019.00054; Big Data in Smart Farming – A review, Agricultural Systems Volume 153, May 2017, Pages 69-80, https://doi.org/10.1016/j.agsy.2017.01.023; The Impact of Big Data on Agriculture, January 7, 2021, https://www.analyticsinsight.net/the-impact-of-big-data-in-agriculture/; A New Global Agriculture: Using Big Data to Bring Farmers Together, http://www.fao.org/family-farming/detail/en/c/1189588/; Digital Technologies, Big Data, and Agricultural Innovation, https://link.springer.com/chapter/10.1007/978-3-030-50991-0_8. In manufacturing, Big Data can be used to gather exceptionally large number of data sets, on different stages of multiple production processes, including data on the products, quality, machine health, and operators. Thereafter, technologies such as AI (and Machine Learning) can be used to analyse and learn new insights from the data, which may be structured or unstructured.

- 3D:

a. As noted above, 3D technologies can be acquired and deployed by an individual, a group of individuals, cooperative, M/SMEs or by large farmers and manufactures. There, 3D, like Robotics, may be considered as cross-cutting in that they fit into both the affordable/inclusive and advanced categories of technologies

b. 3D technology, particularly suited to small-scale manufacturing, can boost the productivity of entrepreneurs, start-ups, and M/SMEs. For technology and innovation actors in this group, 3D, deployed in aspects such as design, R&D or prototyping can make significant difference in productivity and enhance their manufacturing capabilities.

c. Beyond the use of 3D Printing in business applications, which is most common to the majority of users, the technology is extensively applied in medicines (for example, in the manufacture of prosthetics [arms, legs, etc.], hearing aids, artificial body organs e.g., teeth and kidneys. An entire housing unit has been constructed in Mexico, using 3D Printing[20], helping to highlight the prospect of the technology in industries such as housing and construction. 3D technology, used to make shoe designs, can find important use in Rwanda's textile industry.

- **Barriers, enabling environment and opportunities for transformation**

The key barriers and hindrances, that also have implications on the ability of these technologies to foster transformation, relate to

1. Infrastructure

i. Electricity (and water) – The cost of electricity is still quite high when factored into the costs of production. And, in some cases, this cost can become prohibitive for some industry actors.

ii. Transportation – plans are on the way to build railways, to help improve the situation.

iii. Internet and broadband, also data. Use of relays and relay stations, means that this challenge, in the near future, no longer be a major barrier.

2. Capabilities – as outlined in Table 9 above

"If infrastructure stays the way it is today, they cannot effectively support progress in these technologies" (interview response)

- **Technology ranking in order of priority:**
  - AI (and ML), IoT and Big Data
  - 3D
  - Robotics

Table 14 below presents a summary of the key issues to be considered in implementing the advanced technologies for manufacturing that are discussed under this factsheet.

20 World Economic Forum (2019) This start-up is 3D-printing an entire neighbourhood in Mexico, Available at: https://www.weforum.org/agenda/2019/12/3d-printed-homes-neighborhood-tabasco-mexico/

Table 14: Implementing Advanced Technologies for Manufacturing

Technologies			
Key issues	**AI**	**IoT**	**3D**
Main features and objectives	Artificial (computer/non-human) intelligence	Digital transformation in manufacturing	Customised printing of tools and appliances
Status of the technology in Rwanda	Emerging. Currently underexploited. Good potentials for growth	Like AI, IoT is emerging, and currently underexploited. However, there is good potentials for growth	Emerging, growing, significant potentials for contributing to the economy
Existing institutions with capacities to develop and transfer this technology	There are a good number of institutions with capacities that can be leveraged and scaled up (see Table 11 above). However, number, size, quality, and capabilities can be further improved	Similar to AI, institutions with capacities exist in Rwanda (including to CAA, Centre for 4IR (C4IR), AIMS and CMU-Africa, UR Centres of Excellence in AI, and RDB. However, there is need for more empirical evidence to help establish to what extent these actors engage with the manufacturing sector in the use of IoT	Institutions exit in the private sector (e.g., FabLab, SolidWorks, StepRwanda)[1], but there is need for growth and scaling up
Will new capabilities be required? If yes, what will they be?	Yes, capabilities e.g., in machine learning, systems, computing, programming and human behaviours. AI is an advanced technology	Yes. Involves capabilities to connect machines and systems together (as in IoT) and use the advanced analytics and data generated to support decision-making	Yes, capacities are needed in operating 3D printers at advanced levels (technical skills) and software, standards, policies related to individual products
How will this technology address the needs of Rwandans?	Can significantly improve manufacturing efforts geared towards the realisation of MiR	Can help Rwandans strengthen decision support systems, quality management and standards. Thereby, contributing to productivity gains	3D printing can be used to manufacture products quickly and at lower costs than traditional approaches
Main beneficiaries	Manufacturing and allied sectors such as agriculture	The entire Rwandan economy – businesses, manufacturing and allied sectors, government actors and others	Entire Rwanda manufacturing and allied sectors
Approximate number of beneficiaries	Industrial sector accounts for 20% of GDP. With allied sectors added, beneficiation could rise to more than 50% of Rwanda's economy	Primary beneficiary (industrial sector): 20%. Secondary beneficiaries: 50% and possibly more	Primary beneficiary (industrial sector): 20%. Secondary beneficiaries: 50% and possibly more
Main benefits of implementing the technology	1. Better prediction of design failures 2. Improving quality assessments and standards 3. Conducting more efficient demand, inventory, and price forecasts	1. 1. IoT can use advanced analytics to support decision-making. This is essential in manufacturing but also other sectors of the economy 2. Real-time monitoring of manufacturing / production assets 3. Connected operational intelligence and the generation of networks that can support platform technologies discussed in Factsheet 3 above	1. Can provide cost-effective solutions and reduce the cost of manufacturing (custom) products 2. Allows for better prototyping prior to actual manufacturing 3. Facilitates more comprehensive planning processes 4. Can provide on-demand parts services

1 https://digital.hbs.edu/platform-rctom/submission/leveraging-technology-for-global-health-3d-printing-in-rwanda/; https://www.3dprintpulse.com/rwanda/; and https://www.fablabs.io/labs/FabLabRwanda

Technologies			
Key issues	**AI**	**IoT**	**3D**
Gender dimension of the technology	As in STEM filed in general; gender inclusion is less than the optimum desired	Requires improvements. However, data from IoT (and Big Data, etc) may help address current gaps	There is need to include women; youths are involved
Environmental dimension of the technology	Can result in major impacts, not simply from the technology itself but from related equipment and technologies. Effective management is essential to mitigate this	Can result in major impacts if not well managed	Environmental impacts are likely to minimal, especially at low and medium levels of operation
Main disadvantages of implementing the technology	1. Advanced capabilities and skill required 2. May require high-end, expensive, and custom infrastructure – if operated in large manufacturing (industrial) contexts 3. Considerations for sustainability transitions must addressed – as currently. Current evidence indicates that digitalisation, by itself, does not lead to sustainability.	1. Advanced capabilities and skill e.g., in computing, engineering, etc, may be required 2. May require high-end, expensive, and custom infrastructure – if operated in large manufacturing contexts 3. Considerations for sustainability transitions must addressed – as currently. Current evidence indicates that digitalisation, by itself, does not lead to sustainability.	1. More appropriate for small scale manufacturing and individual customised products 2. Not well suited to large-scale production in high quantities e.g., for export market, which is essential to realising the goals of MiR policy 3. Sustainability / SDGs concerns around raw materials, many of which may not be biodegradable 4. May require custom infrastructure
Implementation cost estimate	Low cost is possible; but in general, costs will be medium to high	Medium to high	Low, medium, or high depending on scale of implementation

CHAPTER 6

Technology Implementation Plan (TIP) Framework

6.1 Institutional Mechanism

This Technology Implementation Plan (TIP) provides the institutional mechanism and architecture that are crucial to ensure the implementation and effectiveness of this STI review and TNA. It provides a framework, if effectively operationalised, will support the strengthening of Rwanda's NSI and contribute to the realisation of Vision 2050 and the SDGs. In the TIP framework, MINICT and NCST, working with other concerned ministries, will provide high level government (executive) and technical leaderships, respectively, of the TIP. As government institutions, occupying strategic positions, their ability and experience in providing oversight, alongside the design and implementation of programmes, projects, and policies, to help realize both STI policy and national development agenda of Rwanda, will be vital to the operationalisation of the TIP. MINICT and NCST will help ensure that the goals, objectives, and specific actions outlined in this TIP framework are achieved. Both institutions, working with other actors and stakeholders in Rwanda's NSI (see Fig 6 above), will ensure the establishment of appropriate governance, policy and legislative structures, and resources (capabilities and skills, and funding), necessary for realising the objectives of the TIP.

The MINICT, working with NCST and where applicable, Technology Bank and the consultant, and other NSI stakeholders; must ensure effective coordination and implementation of the TNA TIP framework, promotion, coordination, facilitation, and policy coherence. Table 10 outline roles and responsibilities in further detail.

6.2 Compliance with the SDGs and Cross-sectoral Alignment

Three factors must be taken into consideration implementing the TNA:

1. a focus on the SDGs – that is, ensuring that the TNA implementation addresses issues of gender and inclusivity, poverty, and hunger. And that the choice of technologies deployed do not exacerbate inequality, exclusion, or environmental degradation.
2. alignment with the goals and development objectives of other development sectors in Rwanda such as Education, Energy and Finance.
3. participation of NSI actors and stakeholders in consultative processes that are informed by effective governance mechanism. Effective participation is essential to achieving the level of co-creation, experimentation, reflexivity and learning that is required for successful implementation of this TNA.

The three points will have an important bearing on the success of TNA implementation.

6.3 Roles and Responsibilities

The extent to which the implementation of the findings and recommendations of this TNA is successful will depend on how well the NSI actors (see Figure 6 above and Table 15 below), collaborate and coordinate their resources to deliver the activities proposed. In addition, the implementation will require effective collaboration and partnership with regional (East Africa), continental (Africa-wide) and international development actors. Therefore, it is essential that a good governance framework is developed to guide the coordination of the policies, projects, programmes, and relevant components of the implementation.

Table 15: TNA Implementation Matrix

Responsible Actors: MINICT and NCST (as co-leads), and Technology Bank	
Objective(s)	To help ensure effective coordination and implementation of the TIP framework, promotion, coordination, facilitation, and policy coherence
TNA Target Area	Technology governance and NSI strengthening
Link to STI Policy Objectives	Objective 1: Effective STI governance; Section 5: STI Policy Priority Sectors
Link to Vision 2050 pillars, focus areas	Vision 2050 focus areas (see also Table 1)
TNA Intervention	Develop governance, policy and legislative; logic framework; Theory of Change (ToC); set up expert oversight committee
Short-, Medium- or Long-Term measures[1]	Short Term: Initiate implementation, following report launch Set up implementation governance board Develop Logic Framework and ToC (co-created with NSI actors)
Implementation risks (and possible challenges) and mitigation measures	Risks: resources (capabilities, staff, funding etc) not available, hence activities are delayed Mitigation: engage with NSI actors (national and international) and seek out institutions with possible resources availabilities
Responsible Actors: MINICT[2] and NCST, NIRDA, EASTECO, AUDA -NEPAD, Technology Bank	
Objective(s)	Strengthen cross-sectoral policy coordination across national and regional governments
TNA Target Area	TNA implementation programmes, projects, and policy coordination
Link to STI Policy Objectives	Objective 1: Strengthening STI coordination and cross – pollination
Link to Vision 2050 pillars, focus areas	Scaled up use of modern inputs and technologies to maximize productivity (Pillar #3)
TNA Intervention	Coordinate the review, updates, and integration of relevant policies on STI, research and industry to help achieve the TNA objectives
Short-, Medium- or Long-Term measures	Short Term: In developing the Logic Framework and ToC, ensure alignment with relevant policies and TNA objectives
Implementation risks (and possible challenges) and mitigation measures	Risks: weaknesses in research and policy capabilities Mitigation: where applicable, strengthen the capabilities of implementation teams

1 Short Term: 1 – 6 months. Medium Term: 3/6 – 12 months. Long Term: 1 – 3 years and beyond

2 Where applicable, the lead actor is in bold, to help ensure clear articulation of roles and responsibilities

Responsible Actors: NCST and MINICT, NIRDA, UR, RP	
Objective(s)	Foster effective linkage with NSI actors and stakeholders, especially, academic
TNA Target Area	Improving NSI actors and stakeholders' interactions and linkages
Link to STI Policy Objectives	Objective 2: Increased Scientific and Technology Output
Link to Vision 2050 pillars, focus areas	Strengthening linkages between academia and industry (Pillar #1)
TNA Intervention	Strengthen NSI linkages and interactions; develop appropriate STI indicators; design policy instruments / mix
Short-, Medium- or Long-Term measures	Medium Term: Initiate regular implementation engagement sessions with NSI actors (e.g., quarterly) Develop appropriate STI indicators and policy instruments
Implementation risks (and possible challenges) and mitigation measures	Risks: a) NSI actors fail to attend engagement sessions b) weaknesses in capabilities needed to develop indicators and instruments Mitigation: a) experiment on new engagement approaches, b) strengthen capabilities
Responsible Actors: MINAGRI, RAB, NAEB, UR, RICA, KIC	
Objective(s)	Mapping, selection, and deployment of TNA technologies for Agriculture sector
TNA Target Area	TNA Priority Sector 1: Agriculture
Link to STI Policy Objectives	Section 5: Priority sectors – Food Security and Modern Agriculture
Link to Vision 2050 pillars, focus areas	Pillar #3: Agriculture for wealth creation; market-led and high-tech agriculture
TNA Intervention	Implement technologies for Agriculture sector
Short-, Medium- or Long-Term measures	Short Term: Outline targets specific to agriculture sector in the implementation
Implementation risks (and possible challenges) and mitigation measures	Risks: a) targets not ambitious and unlikely to result in the level of transformative changes desired, b) implementation resources not readily available or inadequate Mitigation: a) ensure targets are bold, SMART, and mission-oriented, b) engage with NSI actors in securing resources availabilities

Responsible Actors: NIRDA, MINICT, NCST, PSF, KIC	
Objective(s)	Develop/design, implement, monitor, manage and coordinate updates of selected platform technologies
TNA Target Area	TNA Platform technology/ies
Link to STI Policy Objectives	Objective 5 - ...Promote strategic partnerships and collaborations... in the fields of Science and Innovation
Link to Vision 2050 pillars, focus areas	Pillar #2: competitiveness and integration
TNA Intervention	Implement platform technology/ies
Short-, Medium- or Long-Term measures	Medium and Long Term: Design and operate selected platform technologies
Implementation risks (and possible challenges) and mitigation measures	Risks: a) selected platform technologies not sufficiently inclusive and unlikely to address the SDGs, b) delays in design and implementation, c) resources inadequate Mitigation: ensure that a) platform technologies are focused on the SDGs, b) there is effective project management, and c) resources are mobilised
Responsible Actors: NIRDA, MINICOM, MINICT, PSF, KIC, UR	
Objective(s)	Mapping, selection, and deployment of TNA technologies for Manufacturing sector
TNA Target Area	TNA Priority Sector 2: Manufacturing
Link to STI Policy Objectives	Section 5: Priority sectors – Local Production and Value Addition
Link to Vision 2050 pillars, focus areas	Pillar #2: Manufacturing for competitiveness
TNA Intervention	Implement technologies for Manufacturing sector
Short-, Medium- or Long-Term measures	Outline targets specific to manufacturing sector in the implementation – in line with Rwandan national Vision and the SDGs
Implementation risks (and possible challenges) and mitigation measures	Risks: a) targets not ambitious and unlikely to result in the level of transformative changes desired, b) implementation resources not readily available Mitigation: a) ensure targets are bold, SMART and mission-oriented, b) engage with NSI actors in securing resources

Responsible Actors: RSB, NIRDA, NCST, Rwanda FDA	
Objective(s)	Oversee standards and quality control of TNA implementation (to support and enhance competitiveness)
TNA Target Area	Ensure that standards and quality control (QA) mechanisms support TNA implementation; if not, develop new/alternative standards; certify that standards are in line with intl. norms
Link to STI Policy Objectives	Section 6: Institutional Framework - Institution in charge of Standards
Link to Vision 2050 pillars, focus areas	Achieving high standards through innovation and technology adoption (Pillar #3)
TNA Intervention	Standards and Quality control
Short-, Medium- or Long-Term measures	Short, Medium and Long Term: Develop standards and QA to mechanisms support TNA implementation; and certify that manufacturing, agriculture etc. standards are in line with intl. norms
Implementation risks (and possible challenges) and mitigation measures	Risks: actors, resources (capabilities, staff, funding etc) are not available to implement this, or activities are delayed Mitigation: start early and engage with NSI (national and international) and seek out institutions with possible resources availabilities
Responsible Actors: NISR, RISA, MINICT, NIRDA, NCST, AIMS-NEI, UR, UNESCO	
Objective(s)	Ensure effective data gathering, information sharing, and communications
TNA Target Area	Data and evidence to support TNA implementation; effective communication among NSI
Link to STI Policy Objectives	Objective 2: Increased Scientific and Technology Output
Link to Vision 2050 pillars, focus areas	Becoming a data-driven economy; powered by technologies – IoT, Robotics, AI and future technologies
TNA Intervention	Data, information, and communications
Short-, Medium- or Long-Term measures	Short, Medium and Long Term: Collect, document, and analyse data, and report on TNA implementation progress
Implementation risks (and possible challenges) and mitigation measures	Risks: actors are not available or not adequately resourced to implement this, or activities are delayed Mitigation: start early and engage with NSI and seek out institutions with possible resources availabilities

Responsible Actors: MINEDUC, Academia (UR, CST/UR, RP, etc.), CMU-Africa, NCST, NIRDA	
Objective(s)	Handle the R&I, training, and capacity building needed to support the TNA implementation and development impact
TNA Target Area	Develop capabilities and skills, a major gap identified across many TNA sectors and the broader NSI
Link to STI Policy Objectives	Objective 4: Human Capital and Knowledge Networks Development
Link to Vision 2050 pillars, focus areas	Universal access to high quality education (Pillar #1)
TNA Intervention	Education, research, and innovation (R&I), training, and capacity building
Short-, Medium- or Long-Term measures	Medium and Long Term: Map STI capabilities and skills gaps, critical to successful implementation
Implementation risks (and possible challenges) and mitigation measures	Risks: actors are not available, inadequately resourced, or activities are delayed Mitigation: engage with NSI and ensure effective resource mobilisation
Responsible Actors: MINECOFIN, FONERWA, DBF, BNR, BRD, RDB, DBF, NCST, AfDB, EASTECO	
Objective(s)	Ensure that appropriate funds are available for the TNA implementation
TNA Target Area	Cost the TNA implementation, mobilise and manage the financial resources
Link to STI Policy Objectives	Objective 3: Increased R&D and Innovation Financing
Link to Vision 2050 pillars, focus areas	Financing Rwanda's economic growth
TNA Intervention	Mobilise and manage funding for implementation
Short-, Medium- or Long-Term measures	Short, Medium and Long Term: Set up, update, and improve mechanisms for resource mobilisation; ensure adequate resources[3] for implementation
Implementation risks (and possible challenges) and mitigation measures	Risks: difficulties with coordination of actors' roles, availabilities and commitments, resource in/adequacy, delays Mitigation: start early, set up coordination mechanisms, engage with NSI actors and ensure adequate resources are mobilised

3 Including actors and institutions, capabilities / skills / expertise, and funding

Responsible Actors: SDGC/A, MINECOFIN, NCST, PSF, UNEP, Technology Bank	
Objective(s)	Ensure TNA implementation is in compliance with the SDGs
TNA Target Area	Align TNA implementation to the SDGs to achieve societal transformation
Link to STI Policy Objectives	Section 5: Priority sectors
Link to Vision 2050 pillars, focus areas	Supporting societal transformation (Key considerations for success #1)
TNA Intervention	Review TNA implementation programmes, projects and policies using SDGs indicators
Short-, Medium- or Long-Term measures	Short, Medium and Long Term: Ensure implementation is aligned with the SDGs
Implementation risks (and possible challenges) and mitigation measures	Risks: implementation is successful but misaligned with key SDGs indicators Mitigation: Use SDGs indicators to track implementation
Responsible Actors: SDGC/A, and independent actor(s)	
Objective(s)	Conduct M&E of the TNA implementation to ensure it is in line with the SDGs; produce annual reports on progress
TNA Target Area	Extend TNA implementation evaluation beyond accountability, and adopt Formative Evaluation (FE) approach
Link to STI Policy Objectives	Section 9: Implementation plan
Link to Vision 2050 pillars, focus areas	Rigorous and effective monitoring and implementation framework (Key considerations for success #3)
TNA Intervention	Monitoring and evaluation (M&E)
Short-, Medium- or Long-Term measures	Short, Medium and Long Term: Collect and analyse data, and conduct M&E to inform and support learning
Implementation risks (and possible challenges) and mitigation measures	Risks: capabilities and/or resources are inadequate; or M&E is misaligned with key SDGs indicators Mitigation: Use SDGs indicators in M&E; if possible, employ FE

CHAPTER 7

Conclusions and Recommendations

This report presents the Science Technology and Innovation (STI) review and Technology Needs Assessment (TNA) for the Republic of Rwanda conducted by the United Nations Technology Bank for Least Developed Countries (Technology Bank) in close collaboration with the Rwandan Ministry of ICT and Innovation (MINICT). In conducting this TNA, the theory of change and overarching objective of the Technology Bank is to help Rwanda build the relevant STI capacity to promote structural transformation of her economy, eradicate poverty and foster sustainable development.

The methodology for the TNA involved a co-creation process of active participation in data and information gathering from relevant stakeholders in Rwanda through well-defined focused group meetings, workshops, and expert interviews. The section presents a summary of the key messages that emerged from the data and the full list of recommendations.

7.1 Key messages

1. **Technologies are needed to help unlock the long-term transformative change and development impacts that could result from the agricultural sector in Rwanda.** From pre-cultivation through cultivation to post-cultivation, and in livestock farming; technologies are needed across the agriculture value chain, if the sector is going to achieve the development aspirations, goals and objectives articulated in the national Vision 2050 and sectoral policies such as the Strategic Plan for Agriculture Transformation 2018-2024 and ICT strategy for Rwanda Agriculture (ICT4RAg). Critical areas of technology need in Agriculture range from technologies to 1) enhance productivity in farm operations such as Greenhouses, Biodigesters, Drones, AI and IoT; and 2) process, store, and transport produce, such as Refrigeration and Robotics; to 3) enable data, information and knowledge gathering and sharing, such as smart/mobile phones and platform technologies. Weaknesses in technology mean that Agricultural productivities continue to be hindered. Addressing the gaps in technologies for agriculture will support Rwanda's ambition of moving into the middle-income country status, contribute poverty reduction and the realisation of Vision 2050 and the SDGs.
2. **Rwanda desperately needs an Advanced Manufacturing sector driven by technologies.** Technologies are essential to realising this ambition, both for the wider economy and for the specifics outlined in policies such as "Made in Rwanda". Evidence presented in Section 4 show that the Manufacturing sector is currently the third largest contributor to Rwanda's GDP, following Agriculture, with Service sector in lead. Despite this position as the second top contributor to Rwanda's GDP; the discussions on TNA Priority 1, Agriculture sector, point to the untapped potentials for the Manufacturing sector. A strengthened manufacturing sector will support progress in agriculture and other sectors. Advancements in the manufacturing sector is essential to addressing many of the challenges identified in the agricultural sector, including processing, storage, refrigeration, and value addition to raw materials, for example in textiles. This calls for challenge-oriented industrial strategy and the importance of stimulating cross-sectoral innovation across the relevant ecosystems. Effective deployment of technologies in the manufacturing sector will help position Rwanda as the manufacturing hub for the region.
3. **To realise the full potentials of technologies in the national development agenda, Rwanda must expand the understanding of technology beyond Information and Communication Technologies (ICTs).** The government of Rwanda has made significant progress in ICTs. However, while the role of technologies in information[1] and communication was recognised as important to progress in Agriculture, the majority of the technologies identified as critical to productivity increases or in manufacturing sector extend beyond ICTs. Consequently, to fully exploit advanced and emerging

1 Gathering and knowledge sharing e.g. among farmers

technologies in manufacturing, agriculture, and others[2], it is vital that the focus and emphasis shifts to technologies over and beyond ICTs to include those discussed in this report.

4. **Robust cross-cutting and sector-specific policies and strategic interventions on technology development, adaptation, diffusion, absorption, and utilisation are paramount if Rwanda is to achieve the aspired vision of becoming upper middle-income country by 2035 and higher income country by 2050.** Existing national policies, such as the Made in Rwanda policy do not go far enough. Sector-specific policies are, for example, needed to address the gaps in standardisation, quality control and traceability – all of which are essential for boosting export and enhancing competitiveness. Considering Rwanda's policy of being a 'proof of concept state' for imported technologies and innovation; it is important to ensure that each sector specific technology policy and/or intervention in Rwanda is effectively contributing to the value chains of imported technologies (and/or innovations). This is vital, if Rwanda is going to leapfrog and become a leader in these technologies.

5. **Policy formulations are important, but they are not, in themselves, sufficient to bring about the long-term transformative change required to move Rwanda to the next levels of development.** Rather, policy formulation must be accompanied by effective implementation, alongside monitoring, evaluation, and interactive learning among actors and stakeholders. To achieve effective implementation, other ingredients are essential. These ingredients include carefully designed (technology, science, and innovation) policy instruments, strengthening of capabilities and skills, availability of funding, and commitment by key actors and stakeholders. Furthermore, implementation must be, where applicable, supported by experimentation on the part of implementing actors, coupled with reflexivity by policymakers. Experimentation would enable implementing actors to 1) try different approaches, 2) learn what works, in what contexts, and under what conditions, and 3) adapt where necessary. For example, farmer-led experimentation on what works in practice at community levels may provide vital lessons on ways to increase productivity, reduce environmental degradation and climate change impacts, or address social challenges such as inequalities and exclusion. Similarly, experimentation at policy levels, that is policy experiments, would help policymakers deepen understanding of new approaches to policymaking that provides that optimises the prospects of implementation and development impacts.

7.2 Recommendations for Rwanda's Main NSI Stakeholders

The Government of Rwanda and Development Partners

1. Address gaps in the governance of the NSI as a way of enhancing the implementation prospects of the findings, the STI policy and other related policies. Establish Technology Governance Board (TGB) – made up of members from the NSI – with oversight functions, to help ensure a good governance structure and effective implementation of the recommendations, programmes, and projects. To achieve the desired outcomes as proposed in this report, the TGB should function across sectors but also with a specific lens on agriculture and manufacturing, whenever relevant.
2. Emphasize effective implementation of the findings; and support the deployment of technology across board, alongside the development of appropriate policy mix, strengthening capabilities and skills, and a focus on the SDGs.
3. Improve access to technologies, especially for women and other marginalized groups, by ensuring affordability. And ensure that specific policies, programmes, and projects are put in place to address gender issues with respect to the technology solutions that have been recommended.

2 Including Energy, Pharmaceutical, and Education not discussed in detail in this report

4. Establish policies, strategies and processes that help Rwandans to better understand the role of technologies in economic growth and social well-being (transformation).
5. Expand the ideas and narratives on technologies as more than ICT or hardware; rather as components that must be deployed across the value chains in all sectors of the economy.
6. Improve linkage and coordination among NSI actors and stakeholders, especially the government-academia linkage, which appears to be significantly weak. In addressing this recommendation, ensure better inclusion of academia in policy and R&D that is focused on technologies and innovation for sustainable development. Inclusivity in the NSI must extend beyond universities (including higher education in general and research centres), and involve other key NSI actors – private sector, digital technology entrepreneurs and start-ups, grassroots innovators, civil society, intermediary actors, and development partners.
7. Increase funding for domestic R&D. For instance, universities specializing in STEM disciplines to conduct R&D relevant to industry/market needs.
8. Refocus education policy on skills development that involves work-based learning and training. This can leverage the success of Workplace Learning Policy currently being jointly implemented MINEDUC, MIFOTRA and MINICOM, in collaboration with development partners. In addition, encourage and support universities and other training entities in the creation of Incubation centres. The incubation centres would then offer trainings that help graduates cope with rapidly changing technologies and market dynamics.
9. Improve STI and digital infrastructure. For example, One Network scheme covers Uganda, Rwanda, and Kenya. However, telephone calls outside of these countries are very expensive and often prohibitive for some industry actors.
10. Strengthen alignment among policies by reducing fragmentation in policies, sectors, and stakeholders, while fostering greater levels of interactions and partnership among ecosystem actors.

Academia

1. Re/Focus research, teaching and learning on addressing the gaps in the STI systems with a view to ensuring that STI effectively contributes to tackling Rwanda's development challenges as articulated in the national Vision 2050.
2. Strengthen capabilities, skills and human capital in innovation, STEM and public policies and policymaking. To achieve this objective, it may be necessary to update the relevant teaching methods and learning practices and curricula on research, innovation, STEM, and digital to the appropriate international standards necessary to placing Rwanda on a world-class status.
3. Strengthen linkages with other NSI actors, especially government, where such linkages exist; and create new linkages where they currently do not exist. Innovation is systemic and is fostered in the atmosphere of interactive learning. Therefore, interactions, learning and effective collaboration with other NSI actors and stakeholders is essential to realising the objectives outlined.
4. Improve staff and student time and motivation in research, innovation, and STEM related fields, with a focus on development impacts. Provide, in particular, special incentives to attract, retain and advance the carers of women and girls in STEM, with clear employability pathways that help mainstream gender in higher education research, innovation, and STEM. In updating the relevant policies on staff, make provision in faculty workload for research in innovation and technology, and provide for dedicated time for engagements and work with industry actors.

5. Increase emphasis on R&D, technology development, policy research, science (or more broadly, STI) for development, the importance of patenting and IPR protection. Where applicable, strengthen existing innovation and technology hubs and Technology Transfer Offices (TTOs) and create new hubs/TTOs where they do not currently exist. Innovation and technology hubs and TTOs in this regard can support co-creation and interactive learning among STI actors, improve linkages and collaboration, and contribute to strengthening the governance of the NSI.

Industry – large, medium, and small (e.g., technology start-ups)

1. For large and medium industry actors, especially; set up dedicated R&D and technology development units, funding streams, policy instruments, and incentives that promote science and innovation, technology development, diffusion, deployment, utilisation, and application in Rwanda.
2. Improve collaborations on technology, R&D, innovation, and capabilities strengthening with NSI actors and stakeholders. Effective collaboration among actors is essential to innovation and improves the prospects of technology development, commercialisation, adoption, and utilisation.
3. Contribute to improving Rwanda's innovation status by refocusing attention on increasing the numbers of domestic technology and innovation outputs, patents, innovation and technology hubs, and support for start-ups and grassroots innovators.
4. Reward employee on pathbreaking and transformative R&D (research/science) outputs that result in the deployment of technology and innovation products that are focused on development impacts.
5. Support academia and other NSI actors in capabilities and skills building that enhances the effective technology deployment in Rwanda.

Civil Society Organisations (CSOs), Innovation Intermediaries, and Service Providers

1. Design and implement technology, science and innovation public engagement events, promotion activities and awareness campaigns with a view to helping NSI actors establish programmes, projects and policy measures that help mainstream technology as an essential input to economic growth and sustainable development.
2. Strengthen the case for increased participation and representation of women and girls in research, STI and STEM. And support NSI actors in capabilities and skills building, and infrastructure development in STI, especially with respect to gender divides and inequality in STEM.
3. Work with NSI actors – especially government, academia, and industry (Triple Helix actors) – in expanding technology, science and innovation opportunities, programmes and projects in ways that help focus greater attention on inclusivity and the SDGs.
4. Engage, critically, with Triple Helix actors in the a) formulation, implementation and evaluation of this TNA and other STI-related policies, b) development of appropriate policy instruments and theory of change that prioritises inclusivity and the SDGs, and logic framework that clearly charts the way for transformative change and c) the governance of the NSI.
5. Design, propose and help advance (policy) measures that strengthens linkages and synergies and fosters greater cooperation and collaborations among NSI actors and stakeholders with a view to enhancing learning, interactivity, and inclusiveness.

Recommendations for Agriculture and Manufacturing Sectors

1. Constitute R&D units in industries. R&D units are essential as markets are dynamic, particularly in agro-processing sub-sector. For example, engagement in R&D explains in part why some firms can introduce diversified products to the markets, while other firms are not so successful in this regard.

2. Deepen understanding and capabilities on (digital) technologies and embrace digitalisation.
3. Develop and implement policies and regulations that foster adoption of standards and quality management systems.
4. Strengthening innovation and manufacturing capabilities through education and specialized skills development.
5. Revise and update existing curricula or create new curricula where applicable; focus on learning.

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Annex 1: Rwanda Development Stakeholders Workshop, July 2021

Institutions represented include:

1. Min of ICT,
2. NCST,
3. RDB and Rwanda Innovation City,
4. Private Sector, PSF,
5. RISA,
6. Emerging Tech experts,
7. Business analyst, and
8. MiR Secretariat at MINICOM.

Annex 2: Stakeholders Consulted and Sources of Data Collection – Sectoral Workshops, Interviews and Focused Group Meetings

1. KIC - Kigali Innovation City
2. MFIs - Microfinance Institutions
3. MINAGRI - Ministry of Agriculture and Animal Resources
4. MINECOFIN - Ministry of Finance and Economic Planning
5. MINEDUC - Ministry of Education
6. MINICOM - Ministry of Trade and Industry
7. MINICT - Ministry of ICT and Innovation
8. NCST - National Council for Science and Technology
9. NIRDA - National Industrial Research and Development Agency
10. PSF - Private Sector Federation
11. TB - Technology Bank (United Nations)
12. UR - University of Rwanda

Annex 3: Validation Workshop Stakeholders – List of Participants and Agencies Represented

1. Yves Iradukunda, MINICT
2. Esther Kunda, MINICT
3. Diana Kamili, MINICT
4. Martine Nezerwa, MINIAGRI
5. Louis Sibomana, NCST
6. Larissa Umulisa, NIRDA
7. Hubert Kageruka, NIRDA
8. Jean-Pierre Ngendabanga, NIRDA
9. Charles Bucagu, RAB
10. Angelique Karekezi, RDB
11. Parfait Yongabo, University of Rwanda
12. Denis Ndanguza, University of Rwanda
13. Rohit Dhawan, Bank of Kigali

Annex 4: Intersection between Agriculture Sector needs and technology solutions

Focus area	Technology needs: Technologies for…	Barriers and challenges with respect to specific needs	Possible technology solutions and opportunities for transformation	Categories of technology solutions
Productivity increase: pre-cultivation	Info and data gathering, modern farming techniques, land preparation	Weak access to relevant information (e.g., on modern farming methods), finance, resources (e.g., land) and infrastructure, etc	Mobile/cell/smart phones; Techs for soil analyses; Network and platform(s) for info/data gathering and sharing; Modern farm machinery, access to finance, policy support	• Affordable and Inclusive technologies • Online systems and platform technologies • Advanced Technologies • E-businesses Technologies
Productivity increase: cultivation	Enhancing crop yield by e.g., reducing production costs, and optimising infrastructure (for example, energy and water) and logistics; smart irrigation, etc	Low productivity; poor access to STI, info/ICT, data and knowledge on modern farm practices and techniques; resource, capabilities, and skills constraints; and others	Precision / smart agriculture techs, green house, smart irrigation, soil, water and land management, solar energy. Examples: Greenhouses, Drones,	• Affordable and Inclusive technologies • Online systems and platform technologies • Advanced Technologies • E-businesses Technologies
Productivity increase: post-cultivation	Reducing post-harvest losses; improving storage, transport-ation, logistics, access to markets, price info and profitability	High post-harvest losses especially in vegetables; further losses during storage and transportation; access to markets, price info and data	Techs for storage, reducing post-harvest losses, sun/air drying, tanning, refrigeration, transportation	• Affordable and Inclusive technologies • Online systems and platform technologies • Advanced Technologies • E-businesses Technologies
Animal production (Livestock farming)	Accessing technical know-how to enhance the productivity in livestock	A major loss point is milk preservation during transportation and storage	With the focus now on milk producing cows; techs e.g., for processing of milk is priority	• Affordable and Inclusive technologies • Online systems and platform technologies • Advanced Technologies • E-businesses Technologies
Value addition	Adding value to raw materials e.g., in the minerals, textiles and garment, coffee supply chains and other products, before exports	Deeper analyses – which looks at the value chain – such as structural issues, market access, access to raw materials, etc	Technologies for value-addition to agricultural products and including processing, packaging, branding, marketing, transportation, and logistics	• Online systems and platform technologies • Advanced Technologies • E-businesses Technologies

Focus area	Technology needs: Technologies for…	Barriers and challenges with respect to specific needs	Possible technology solutions and opportunities for transformation	Categories of technology solutions
Information sharing and communi-cations	Accessing and using farming and market info (e.g., pricing, product demand, market size, innovations in agric., capacity building exercises etc)	Farmers currently have weak access to information and knowledge that may help them increase productivity, access markets, sell their goods and enhance their well-being	Mobile/cell/smart phones, data networks; platform(s) and supporting technologies	• Online systems and platform technologies • Affordable and Inclusive technologies • Advanced Technologies • E-businesses Technologies
Standardis-ation, traceability, and quality control	Ensuring standards in products, e-traceability of agriculture and food systems products, goods, and services; certifications, and quality control	Ability to ensure accurate data and information on the origins of products (e-traceability of agriculture and food), adherence to standards, certifications, and quality control by producers	Standards, such as ISO's and others applicable to foods and drugs	• Advanced Technologies • Online systems and platform technologies • E-businesses Technologies
Finance	Finance is essential for progress in STI, R&D (formal and informal) and knowledge generation	Farmers remain one of the most marginalised groups in terms of securing formal loans	Credit-rating system (software or platform)	• Online systems and platform technologies • Advanced Technologies • E-businesses Technologies
Capabilities and skills	Capacity strengthening e.g., on production practices (such as fertilizer application and optimisation), quality, standards, and pricing; market access and business development; and others	Weaknesses in capabilities and skills continue to hinder the adoption of emerging technologies and innovations; need to support the adoption of modern techs such as AI and blockchain	Context-specific technologies to enable capacity strengthening at low- and high-tech levels; alongside appropriate platform technologies and networks	• Affordable and Inclusive technologies • Online systems and platform technologies • Advanced Technologies • E-businesses Technologies

Annex 5: Intersection between Manufacturing Sector needs and technology solutions

Focus area	Technology needs: Technologies for…	Barriers and challenges with respect to specific needs	Possible technology solutions and opportunities for transformation	Categories of technology solutions
Productivity increase	Support optimization, improve resource efficiency and savings, and reduce waste	Gaps in technology[1], infrastructure, capabilities, governance, standards, awareness of the role of techs, finance, and policy support	3D, 4D, Automation, AI, IoT, Big Data	• Advanced Technologies • E-businesses Technologies • Online systems and platform technologies
Cost of production	Reducing the cost of production e.g., by lowering labour or inputs (e.g., electricity) cost	Inability to effectively develop, appropriate or deploy techs such as solar, robotics and AI	Robotics (a bit futuristic for Rwanda) but can help in the reduction of production costs, increase of productivity	• Advanced Technologies • E-businesses Technologies • Online systems and platform technologies
Value addition, industrialis-ation, competitiv-eness, upgrade and promote MiR products	Value addition to raw materials, boosting competitive industrial sector. For example, 1) value addition to minerals, 2) spare parts to machines, 3) standardi-sation	Difficulties with M/SMEs ability to process raw materials into semi-finished products. And supply semi-finished products to larger firms and industries	Standards, such as ISO's and others applicable to foods and drugs	• Online systems and platform technologies • Advanced Technologies • E-businesses Technologies
Information sharing and communic-ations	Increasing awareness of technologies for manufact-uring, data gathering, marketing, info sharing, matching demand with supply	Need for techs that increase interaction among ecosystem actors, collaboration and therefore innovation	Set of platforms(s) and supporting technologies	• Online systems and platform technologies • Affordable and Inclusive technologies • Advanced Technologies

1 In this instance, used in the broad sense to cover technology development, deployment, appropriation, dissemination, adoption and management

Focus area	Technology needs: Technologies for…	Barriers and challenges with respect to specific needs	Possible technology solutions and opportunities for transformation	Categories of technology solutions
Processing, packaging, and transport-ation	In animal (livestock) farming, for example, the focus on livestock for milk purposes means that there is high demand in milk processing, storage, transporta-tion, and related activities	In textiles for example, technologies can help in tanning of hides and skins to avoid or reduce the use of chemicals, resulting in less environmental degradation.	3D, 4D, Automation, AI, IoT, Big Data	• Affordable and Inclusive technologies • Online systems and platform technologies • Advanced Technologies • E-businesses Technologies
Standardis-ation, traceability of manufact-ured products, and quality control	Ensuring standards in products, e-traceability of products, goods, and services; certifications, and quality control	Challenges with standards of manufactured goods, which often do not meet international standards. This reduces progress of the MiR by hindering competitiveness	Example: Quality Management Systems (QMS), which are essential for various reasons, e.g., to improve quality and traceability of manufactured products	• Advanced Technologies • Online systems and platform technologies
Infrastru-cture, logistics and transport	Value addition to raw materials, boosting competitive industrial sector. For example, 1) value addition to minerals, 2) spare parts to machines, 3) standardi-sation	Difficulties with M/SMEs ability to process raw materials into semi-finished products. And supply semi-finished products to larger firms and industries	Standards, such as ISO's and others applicable to foods and drugs	• Advanced Technologies • Online systems and platform technologies • E-businesses Technologies
Capabilities and skills	Capabilities and skills are needed to understand, absorb, and utilise modern/advanced techs	Skills gap remains a major hinderance in the manufacturing sector	Context-specific technologies, frameworks, and policies, must underpin capacity strengthening at low- and high-tech levels. Platform technologies deployed must be multi-sectoral	• Affordable and Inclusive technologies • Online systems and platform technologies • Advanced Technologies • E-businesses Technologies


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