Understanding knowledge systems and what works to promote science technology and innovation in Kenya, Tanzania and Rwanda

Contract Reference: PO8093

OJEU Publication Reference Number: 2017/S 184-377250

Final Report - October 2020 (Revised)

Submitted by

UNIVERSITY of GREENWICH

NRI | Natural Resources Institute

In collaboration with African Centre for Technology Studies (ACTS) Kenya, Commonwealth Scientific and Industrial Research Organisation (CSIRO) Australia, Science Policy Research Unit (SPRU) - University of Sussex Business School and Science, Technology, Engineering and Public Policy (STEaPP) at University College London (UCL)

Core Project team

Natural Resources Institute (NRI), University of Greenwich

- **Professor Andy Frost (PI)** a.i.frost@gre.ac.uk
- **Dr Apurba Shee** a.shee@gre.ac.uk

African Centre for Technology Studies (ACTS) Kenya

- **Dr Joanes Atela** j.atela@acts-net.org
- **Nora Ndege** n.ndege@acts-net.org

Commonwealth Scientific and Industrial Research Organisation (CSIRO) Australia

- **Professor Andy Hall** andrew.hall@csiro.au

Science Policy Research Unit (SPRU) University of Sussex Business School

- **Professor Fiona Marshall** f.marshall@sussex.ac.uk
- **Dr Tommaso Ciarli** t.ciarli@sussex.ac.uk
- **Dr Jonathan Dolley** j.dolley@sussex.ac.uk
- **Dr Hugo Confraria** h.confraria@sussex.ac.uk

Science, Technology, Engineering and Public Policy (STEaPP) at University College London (UCL)

- **Professor Joanna Chataway** joanna.chataway@ucl.ac.uk

KSI Country focal points

Kenya – University of Nairobi

- **Professor Shem Wandiga** wandigas@uonbi.ac.ke

Tanzania – University of Dar es salaam

- **Dr Kelefa Mwantimwa** mwantimwa3@gmail.com

Rwanda – University of Rwanda

- **Professor Nelson Jumba** mutatinak@gmail.com

Acknowledgements

The authors are very grateful to our teams at the University of Nairobi in Kenya, University of Dar es Salaam in Tanzania and the University of Rwanda – in addition those individuals who have helped form the communities of practice, and advisory panels for the project and others who have attended the various stakeholder engagements. Their enthusiasm was encouraging, and their openness and honesty was critical to the success of this project.

Table of Contents

Abbreviations and Acronyms

ADB	African Development Bank
AU	African Union
ACTS	African Centre for Technology Studies
CBD	Centre for Biological Diversity
CoP	Community of Practice
COSTECH	Commission for Science and Technology (Tanzania)
CSIRO	Commonwealth Scientific and Industrial Research Organisation, Australia
EAC	East African Countries
EARIH	East Africa Research and Innovation Hub
FCDO	Foreign, Commonwealth and Development Office
GDP	Gross Domestic Product
GERD	Gross Domestic Expenditure on Research and Development
ICT	Information and Communications Technology
IPAR	Institute for Policy Analysis
IS	Innovation Systems
JKUAT	Jomo Kenyatta University of Agriculture and Technology
KENRIK	Kenya Resource Centre for Indigenous Knowledge
KS	Knowledge System
KSI	Knowledge Systems Innovation
LMICs	Low- and Medium-Income Countries
M&E	Monitoring and Evaluation
NACOSTI	National Commission for Science, Technology and Innovation
NCST	National Commission for Science and Technology
NIH	National Institutes of Health
NIRDA	National Industrial Research and Development Agency
NRI	Natural Resources Institute (University of Greenwich)
NRIF	National Research and Innovation Fund
NSI	National Systems Innovation
PPP	Public Private Partnership
R&D	Research and Development
RoI	Returns on Investment
RS	Research Systems
SDGs	Sustainable Development Goals
SGCI	Science Granting Councils Initiative
SIDO	Small Industries Development Organisation
SME	Small and medium-sized enterprises
SPRU	Science Policy Research Unit (University of Sussex)
S&T	Science and Technology
STI	Science, Technology and Innovation
STISA-2024	Science, Technology and Innovation Strategy for Africa 2024
SU	Strathmore University
TAKNET	Tanzania Knowledge Network
TIRDO	Tanzania Industrial Research and Development Organisation
ToC	Theory of Change
TORS	Terms of Reference
TVET	Technical Vocational and Educational Training
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UoR	University of Rwanda
VAR	Vector AutoRegression
VETA	Vocational Educational Training Authority
WB	World Bank

Executive Summary

Background and Approach

Science, Technology and Innovation (STI) could play a critical role in addressing the Sustainable Development Goals (SDGs). To do so, it will require an STI planning, investment and evaluation approach that in addition to economic growth, more explicitly targets social inclusion and environmental sustainably to achieve balanced growth. This will entail a much closer alignment of STI policy with development priorities and will require patterns of governance, participation and cooperation, that encourage a wide set of stakeholders to steer the priorities for STI investment and capacity building and the outcomes that these seek to achieve.

Such an approach needs to look beyond traditional science and technology providers – although it is essential to strengthen these too - to include the full range of knowledge production sources and innovation processes that society has to offer. The implications are profound and while there is agreement that STI is a critical part of the way forward, there is less clarity on how to proceed.

It is against this backdrop that the UK Government through the FCDO East Africa Research and Innovation Hub, funded a pilot study to develop a practical approach to capacity development and investment in knowledge systems, in three East African countries; Kenya, Rwanda and Tanzania. The primary consideration of this research was to amalgamate robust international evidence and country level research to inform a clear, contextualised and practical approach for national decision makers in Kenya, Rwanda and Tanzania and their respective partners. The core of the research approach presented within this report iterates between evidence collection, concept development, concept testing and refinement; underpinned by a comprehensive stakeholder engagement.

Reframing STI policy for sustainable development

Emerging from a review of literature is the need to build a much more comprehensive picture of the STI environment than that provided by current analyses and policy framings. The sustainable development agenda reframes the sphere of STI policy ambitions, science excellence and economic growth, to making direct contributions to sustainable development. There is increasing recognition that STI policy has overlooked a significant arena of innovation activity that takes place in the informal sector in emerging economies.

This study contends that whilst important and useful, existing dominant research and innovation policy conceptual frameworks can skew analysis, data collection and investment strategies impeding efforts to bridge STI and national development goals in low- and medium-income countries. A key issue is that important features of local contexts are regularly omitted from analysis and that this omission steers and distorts investment in unproductive ways. Another is that standard metrics associated with those dominant paradigms are focused on inputs and outputs. A growing body of theory and evidence about STI policy and policy frameworks is emerging, shedding light about changes needed so that low-and medium income countries can reap the rewards of investment. In this study, the overall intent was to build on this emerging body of insight and make a first attempt to develop a more systemic approach to understanding and resolving the need for a new STI policy conceptual framework to better align STI to development needs and goals.

Development of a practical (KSI) conceptual framework

Two practical insights arise from the need to develop a more comprehensive picture of the STI ecosystem, both of which were implemented during this study. First, a need to use a range of different analytical diagnostic tools/perspectives to build and triangulate difference pieces of evidence from across micro to macro scales and reveal different domains of knowledge and innovation related activities. Second, as the KSI conceptual framework is not a normative view of STI capacity there needs to be an embedded process of stakeholder engagement to ensure that new options are aligned with specific sustainable development challenges being faced in a particular country context. This framework also helps highlight components of the knowledge system that are currently neglected in STI policy analysis and investment.

The KSI conceptual framework as developed and used by this study demonstrates potential to deliver the more comprehensive understanding of the STI investments required to address the SDGs; illustrated in the diagram below.

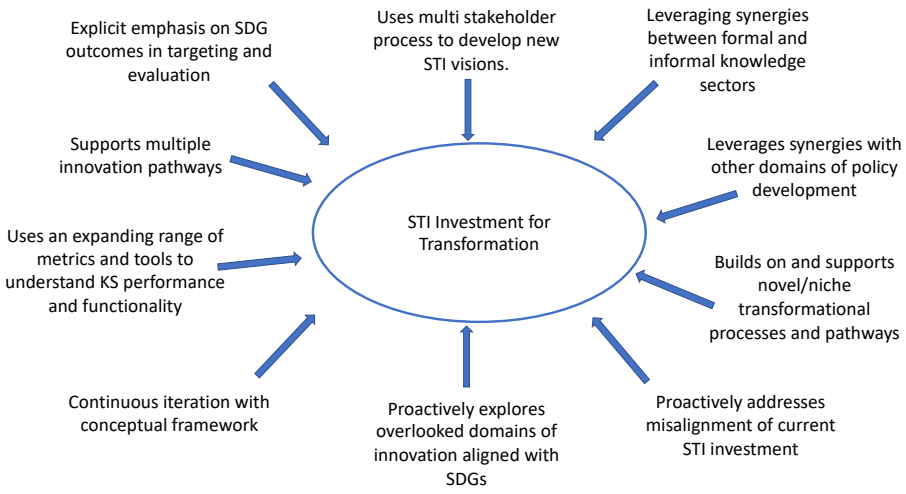


Diagram to summarise some of the key aspects of STI investment for transformation that guide the KSI practical knowledge system concept

Concept testing and refinement in Kenya, Tanzania and Rwanda – what did it tell us?

Mapping the current STI context: This study explored the current STI context in Kenya, Tanzania and Rwanda. This helped develop a broad picture of the STI context and the policy perspectives that frame this. It was also useful in highlighting the importance of bridging gaps between knowledge production by research and knowledge use by the private sector and others. However, current policy perspectives in the region, particularly the extensive use of national systems of innovation framing means that less attention is given to the purpose to which innovation is directed (other than economic growth) or the values that underpin decisions and goals.

While policy documents for the region are very broadly framed towards sustainable development there is an unclear line of sight between these broad ambitions and the formulation of national STI policy. This is one explanation of why STI investments are limited in contributing to achievement of the SDGs and national development goals. This study highlights a widespread lack of clarity about the purpose to which STI investments are being deployed and suggests that existing STI policy frameworks in the three countries, and the processes through which priorities and future directions are set, could be reframed to account for the explicit and widening impact agenda implied by the SDGs and national development goals.

The mapping of the STI landscape in the three countries reveals important differences between the three countries, including the role of state and non-state actors in knowledge production, the levels of research capacity, the level of sophistication of the private sector and its related capacity of knowledge use and innovation, different governance arrangements for STI policy and priority setting and different political and development histories, trajectories and priorities. There are also similarities, for example challenges of translating research into innovation and impact, large informal sectors that receive limited attention from the STI policy and distortions of research priorities arising from international research collaboration. From the perspective of our KSI conceptual framework these differences are noteworthy because this underlines the need to approach STI investment planning in a context specific way, exploring in more detail the way STI investments are performing and the nature of new STI opportunities and view-points in these particular contexts.

This study exposes major gaps in the evidence base concerning STI investment performance in relation to development goals and particularly with regard to sustainable development. Without systematic and long-term monitoring of the outcomes of specific interventions it is impossible to assess the impacts of contemporary patterns of investment in relation to the SDGs.

What did examining STI investment in country contexts reveal?: By way of a series of case studies this pilot project took a deeper dive into the context of the three countries, exploring the diversity of different types of

STI investment and investigating what this can reveal about what is working, what isn't and why and identifying promising areas of knowledge and innovation activity overlooked is current STI priorities.

Despite the lack of impact evidence, it is possible to identify a diverse set of STI interventions and knowledge related activities with SDG intent or value and to develop a picture how these interventions are playing out. A number of important points emerge from assessing the diversity observed. It appears that what can and indeed what needs to be considered part of each of the countries' STI investment portfolio is probably much wider than that is reflected in standard STI policy reviews. Clearly, many initiatives are underway that have relevance to the SDG agenda that could not only be built up, but could also be a source of lessons for a future facing STI agenda. Our study reveals many of these initiatives have emerged "in context". For example, in Rwanda, where research capability is still developing, the emphasis has been put on "home grown" "Made in Rwanda" as a way of tapping into a wide range of formal and informal knowledge sources. In contrast, in Kenya with its strong ICT, research and private sector history, interventions are being made to build on these strengths and resources. Tanzania has an entirely different political and STI history and is pursuing options of state led industrialisation around SME development. So while the patterns of diversity that have been observed suggest the green shoots of a different sort of knowledge system emerging, novel approaches cannot simply be transferred across countries and regions, but need to be understood and supported *in-situ*. Our KS concept also places value on creating the conditions for amplifying these promising initiatives as well as encouraging STI policy to enable the emergence of an expanding range of these types of experiments and to leverage them for SDG impacts.

Despite stressing the importance of context in the emergence of these initiatives, there are also some cross-country patterns in investment and interventions that are apparent:

- **Linking research to the private sector.** Initiatives that seek to develop partnership between universities and other public research organisation in order to "commercialise" research finding and or establish new business offering.
- **Bridging informal and formal sectors**. These take many forms including: searching for solutions in informal sector innovation, particularly because of the informal sector's ability to tap into the needs of poor communities; or extending training and regulation to the informal sector to upgrade skills and practice.
- **Enterprise development.** These can take the form of business incubation hubs to help develop ideas into business opportunities. In countries where the private sector has limited capacity this might for example, involve developing SME through capability or technology upgrading.
- **Knowledge sharing platforms and networks**. There is considerable diversity of these initiatives that range from long established civil society networks to purposeful interventions targeting missing knowledge brokering mechanisms in particular domains of knowledge production and use.

What can we say about why STI investments are not delivering to the national development agenda? While clearly it is not universally true that STI investments are not contributing to the national development and SDG agendas, there are causes for concern and indeed a founding rationale for this pilot project. The evidence and analysis generated by this project suggests that there is not one single explanation of STI's under delivery. Rather there are a clutch of systemic problems that play out at different scales in the three countries in remarkably similar ways.

1. the explicit and implicit use of national systems of innovation as the dominate framing of the policy narrative in the three countries – at a time when the performance criteria are expanding beyond economic growth, it should not be surprising that STI investments of the past are no longer delivering now that the goal posts have been moved;
2. the lack of evaluation of STI performance e.g. our economics work highlights the difficulty in judging the impacts of STI investments as there are both methodological challenges and substantial data gaps;
3. concerns of distortion and perverse outcomes of STI investments e.g. our bibliometric analysis clearly illustrates the how international collaboration dominates and skews research effort away from SDG relevant topics and more generally away from local development agendas;
4. range of capacity issues e.g. our case studies show weak links between research and research users; underdeveloped research capacity, lack of knowledge brokering functions etc.

Identifying opportunities for amplifying SDG relevant and overlooked STI approaches: One of the key findings of this pilot study was the plentiful supply of promising activities in both the informal sector and in domains outside the usual STI policy sphere of interest in each of the three countries. In all three countries there is significant informal sector knowledge activity of high relevance to local communities and the SDGs. These tend not to currently be part of the mainstream STI conversation and thus opportunities to be an integral part of wider transformative change are overlooked in STI planning and investment. Our study provides evidence that there are a significant number of novel initiatives, some of which are covered within our case studies, which drive social innovation but also product and service innovation. These might contain disruptive models of innovation. Importantly, they can include the potential to strengthen key knowledge system interactions and nurture a wider STI landscape that is conducive to SDG aligned outcomes.

Did the stakeholder processes work? Great enthusiasm was encountered during the stakeholder engagements in all three countries which generated much insight, provided challenge to the conceptual approach and allowed the findings to be grounded. This project deliberately set up structures e.g. the communities of practice that could provide a foundation for further work in the revisioning of future STI investment strategies. This pilot study has created an appetite for a different type of STI-related discussion; social capital that could be built upon.

Recommendations

It is important to stress here that significant STI analysis in the target countries has already been undertaken and that these point to many issues related to the thematic focus and prioritisation of STI investments as well as issues related to the functionality of innovation systems. This study does not repeat the findings of these studies (patterns of R&D investment etc) but focuses on novel investment opportunities that arise from the additionality of the KSI conceptual approach. These include potential starting points under the following:

- **Strengthen and prioritise STI investments in knowledge generation, translation and brokerage by intermediary institutions and platforms e.g. innovation hubs and communities of practice in addition to governance and accountability frameworks that ensure STI investments are aligned to SDGs and broader national commitments**.

- **Ensure that future investments leverage better linkages and actively promote partnerships between formal and informal sectors**.

- **Work to make sure that STI investments are inclusive and incorporate broader views and perspectives and leverage a range of diagnostic tools/approaches when making policy and investment decisions**.

This pilot study has identified the potential of a practical knowledge system approach and also the limitations in terms of what can be done with current data sets. The following recommendations aim to provide practical steps in taking this concept forward and/or addressing limitations observed during this study.

- **Further testing the approach in strategic planning exercises** – our study has been a successful pilot which forms the basis that could be rolled out and could help build and support e.g. FCDO research and innovation hubs and Science Granting Council Initiatives;
- **Build on the social capital created by this pilot study** – our study established communities of practice that could form promising focal point for further work;
- **Invest in research on STI metrics –** our study highlights major limitations regarding the findings that can be derived from existing datasets (the same datasets that are clearly being used to inform current decision making) and offers a number of practical steps to address these limitations;
- **Invest in robust and continuous impact evaluation of STI investment and use this to guide investments and policy decisions** – our study highlights significant gaps in the data available and expresses caution on the limits to the existing macro analytical tools as a means to inform decision-making. We provide a number of practical next steps to set the foundation for moving forward.

Section 1: Introduction

The sustainable development agenda is a response to a new class of challenges that call into question current patterns of human activity in relation to production and consumption, in relation to access and distribution of resources and in relation to the way these processes and patterns of human activity are governed and directed. Broadly these challenges relate to environmental sustainability of the resource base and the planet as a whole and the crisis of unbalanced patterns of growth that are failing to eradicate poverty, inequity and food, water and energy resource insecurities. These are global scale issues but have particular poignancy and manifestations in low- and middle-income countries (LMICs) where poverty is widespread and where climate change is a major threat to already fragile and degraded environments.

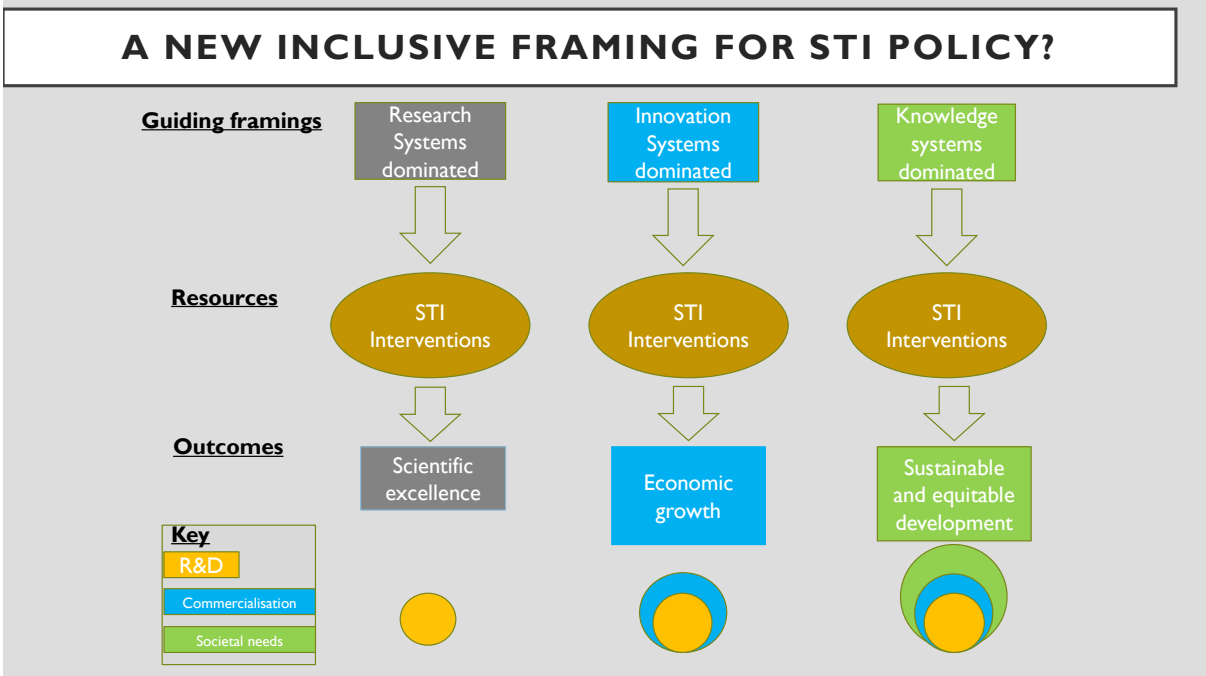
Science, Technology and Innovation (STI) could form a critical plank in addressing these challenges. But that will require of a form of innovation that is much more deeply embedded in society than it has been in the past. It will entail a much closer alignment of STI policy with development priorities in a particular country and will require patterns of governance and participation that give a wider set of stakeholders' ownership of both the priorities and the outcomes of the innovation process. Building this new form of innovation capacity will need to look beyond traditional science and technology providers – although it is essential to strengthen these too - and will need to embrace the full gamut of knowledge production and use and actors and processes that society has to offer. While few would argue against the need to give this STI question urgent attention, there is much less clarity on how to proceed. What sort of capabilities need to be built? What would new forms and patterns of investment look like? How can the performance of existing and new investments in this domain be evaluated? And perhaps most fundamental of all what would an overarching framework look like that could guide policy and practice in prosecuting the new form of innovation action that the sustainable development agenda demands? We believe that only by providing some fresh direction can the ambition of creating sustainable and locally owned STI capacities and processes be achieved.

The overall aim of this pilot project reported here, under the working title, Knowledge Systems Innovation (KSI) was to propose a practical and context specific knowledge system (KS) concept for Kenya, Tanzania and Rwanda, informed by appropriate international evidence of what works in innovation and research system approaches. Part of its rationale is founded on a major paradox in international development practice, policy and investment. On the one hand there is widespread recognition of the need to invest in STI capability in LMICs (Cirera and Maloney, 2017), but on the other hand there is limited evidence of how this can best be achieved. The idea of a national research or innovation system or ecosystem has been articulated through a number of different conceptual traditions, approaches and policy framings. However, these have often emerged in the context of high-income countries, with evidence of what works relating to these contexts. The importance of understanding the context specific nature of knowledge production and use and associated practices and capabilities, also sometimes known as national styles of innovation has in many cases been lost (Arocena et al, 2018). There has often been a tendency to try and use lessons and insights to develop standard models of research and innovation systems to guide policy and investment across a range of contexts rather than focus on the way in which those frameworks might facilitate productive policy learning (Chataway, 2019; Srinivas and Sutz, 2008). The importance of context in knowledge generation and dissemination goes beyond the ideas of Cirera and Maloney (2017) about the importance of management and other complementary factors. It focuses also on the misalignment of knowledge production with social and economic goals in particular contexts.

The primary consideration of this research was to amalgamate robust international evidence and country level research to inform a clear, contextualised and practical approach for national decision makers in Kenya, Rwanda and Tanzania and their respective partners. The core of the research approach presented here iterates between evidence collection, concept development, concept testing and refinement; underpinned by a comprehensive stakeholder engagement process. This was a challenging task. From the outset, we recognised there are conceptual challenges in making direct connections between investments in STI and economic, social and environmental impacts. A further challenge associated with developing the new concept is that most secondary data available has been collected through the frame of an innovation system and as a result there is a considerable gap in the data requirements to populate the wider analysis implied by a KS perspective. This also flows into engagements with stakeholders whose understandings are framed/influenced by previous STI policy paradigms – research systems and/or innovation systems.

Given this, a legitimate opening question is **why propose knowledge systems as a new framing for STI policy?** Figure 1 below presents the dominant framings to date, of research and innovation systems alongside that of KS showing the evolution of driving forces. The first, research-dominated, relies heavily on the idea that we should be led by investment in excellent science and that automatically leads to social and economic benefit and if market failure could be addressed also then all the better. The second, innovation-dominated, was a way of reframing policy on the basis of systems failures because correcting for market failure was seen to be insufficient. Now STI policy also needs to address sustainability and equity failures and the proposed KS dominated approach comes into play providing a more inclusive framing. This approach builds on work that many in the innovation systems community, and the transformative innovative policy world, have been undertaking.

Figure 1 Why is a knowledge system framing being considered now?



Having now introduced the broad concept and rationale as to why a different approach is required this pilot project set out to answer three key questions:

1. Can we develop a practical concept that provides fresh explanations of the ability of STI investment to contribute to balanced growth impact i.e. aligned to the SDG agenda of inclusive and sustainable and smart growth? [See section 3 below];
2. Can we develop an economics approach that can identify the impact and alignment of the investments in the target countries and what are the feasibility considerations and limitations of this work? [See section 4 below].
3. Using the practical concept, can we provide (a) an explanation and evidence of what is working or not in Kenya, Tanzania and Rwanda? And (b) identify new opportunities to strengthen the SDG impact of STI investments [See section 5 below];

The following sections describe the conceptual and methodological approaches that were undertaken to develop and implement a practical KS in Kenya, Tanzania and Rwanda, what we found to be working (and also what was not) before concluding on a series of practical recommendations that could be actioned as potential next steps.

Section 2: Developing a practical concept for characterising the knowledge system in Kenya, Tanzania and Rwanda.

In addressing the first question, could this study develop a practical concept that provides fresh explanations of the ability of STI investment to contribute to balanced growth impact i.e. aligned to the SDG agenda of inclusive and sustainable and smart growth? The answer is positive with this study providing the rationale and practical basis for a new conceptual approach, but this concept is at a pilot scale and would require further work to substantiate the approach. The sections below outline the conceptual and methodological approaches used by this study to provide potential to understand to deliver the more comprehensive understanding of the STI investment context implied by both national development agendas and that of the SDGs.

Study question 1
Can we develop a practical concept to characterise the knowledge systems in Kenya, Tanzania and Rwanda to provide fresh explanations of the ability of STI investment to contribute to balanced growth impact?

Yes but at a pilot scale.

This study proposes a practical conceptual framework termed a transformative KS perspective – a system that has a sufficient set of STI investment and capacities to drive transformational change necessary for balanced and sustainable growth.

Importantly, this concept complements existing approaches – it does not seek to belittle them.

2.1 Conceptual approach

A growing body of research looks specifically at innovation in relation to sustainable development and the implications of placing inclusiveness and sustainability at the core of global development aspirations. There are a number of key messages from this literature as follows:

Innovation trajectories tend to have a high degree of path dependency, with science and technology locked into supporting these trajectories. For example, R&D focused on supporting food systems which are dependent on high external input agriculture reinforces that mode of agricultural production. Even though global development trajectories of the past have advanced economic growth, they have been less effective in achieving social development and environmental sustainability. The SDGs are thus a call to break these path dependencies and to shift to new and more sustainable trajectories of innovation and development.

The sustainable development agenda draws attention to the need for transformation of existing systems, rather than incremental improvement or optimisation. This implies the need for deep system changes – system innovation – as a prerequisite, or at least a companion to innovations concerning the components of the system. Component innovation involves the deployment and substitution of individual technologies, policies and institutional designs. In contrast, system innovation involves reforming or adapting an interlocking set of policies, values, practices and technologies, power and politics that shape innovation directions and priorities. Examples of transformational change may be the shift to renewable energy systems or the shift to an inclusive, shared value business ecosystem.

This agenda of transformational change is therefore not just about the transfer of technology from research to end users, or the use of the market to diffuse this technology, but also a much wider set of sources of (formal and informal) knowledge and innovation that can help break the path dependency of existing innovation trajectories. This helps new modes of production and consumption emerge and demonstrate the possibility of new systems that can disrupt the existing practices and systems. For example, the disruptive effects of M-Pesa, and its ability to provide inclusive financial services, emerged from outside the formal science and technology environment and was seen as a pioneering activity that catalysed wider changes (Onsongo and Schot, 2017).

Recent research also points to transformation as a deeply political agenda. While this means that political economy issues need to be navigated, it also points to transformation being a highly context specific process where priorities and directions need to be decided and pursued locally. From an STI viewpoint this means that capacity building of innovation ecosystems needs to be framed and be aligned to the particular development aspirations of the respective country. For example, a country might aspire to achieve inclusive employment by supporting hi-tech start-ups. This would require different capacity building investments to a country that aspired to develop sustainable agri-food systems by reaching out to its diaspora to access sustainability technology. In reality, all countries will have multiple aspirations and will need to develop different sorts of

capacity. However, the key message is the need to ensure that capacities are aligned to macro level development aspirations. The literature refers to this as the "directionality" of innovation. In other words, its alignment to the development performance of the production and consumption systems innovation is supporting (see Chataway et. al., 2017 and Daniels, 2020).

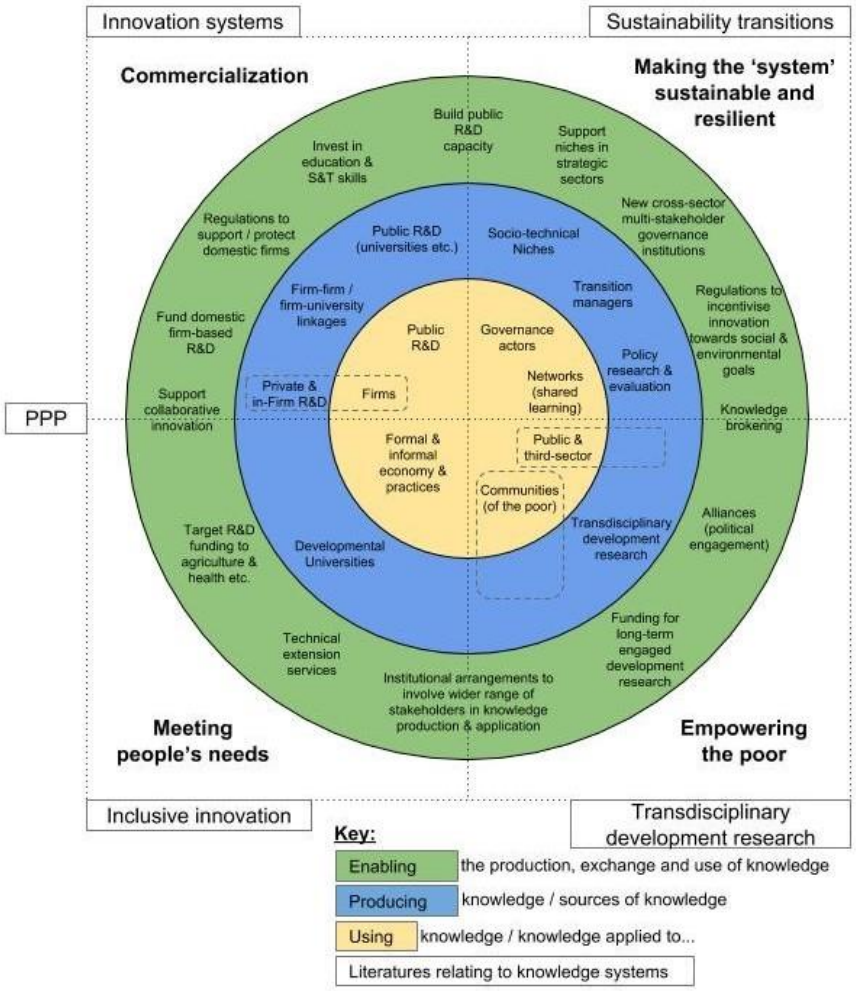
Knowledge, innovation and the informal sector

There is increasing recognition that STI policy has over looked a significant arena of innovation activity that takes place in the informal sector in emerging economies (Kraemer-Mbula and Wunsch-Vincent 2016). In part this oversight arises from biases in innovation studies that suggest that informal innovation is second rate (Kumar and Bhaduri, 2014). It also remains unobserved in part because it is difficult to define and quantify by usual standards and norms. However, in part it is precisely this diversity of forms, often highly demand led in low income economies that that makes it such a powerful mode of inclusive innovation (Links, Hart and Jacobs, 2014). Two recent collections of case studies and analysis focusing on Africa and Asia (Kraemer-Mbula and Wunsch-Vincent 2016; Muchie et al 2016) document the contribution of informal sector innovation to outcomes relevant to an inclusive and sustainable development agenda, particularly in the areas of health care, low cost products, and employment creation. While this and another analysis recommend that STI policy needs to give great attention to informal innovation, Cozzens and Sutz (2014) explain that a significant part of the challenge is that most innovation policy and analytical framing struggle to consider the role of this source of knowledge and that frameworks need to be adapted to account for this overlooked domain of creativity.

Having recognised the importance of informal sector, much more challenging is the question of how to engage with and support the sector? There are a number of suggestions although little consensus. A building block for greater policy attention is to devise better measures of informal sector activity: whether this is feasible or even ethical remains untested. Adapting intellectual property regimes to incorporate and protect informal sector innovations has been argued by some. However, the grass roots actors in this domain such as Anil Gupta and the Honeybee Network argue that IP protection increased competition between informal sector players, where the priority is to encourage networks among them to share knowledge. Another suggestion has been to adapt business support and investment programmes to the needs of the private sector. However, this is often accompanied by a registration process that is not only costly, but can be seen as attempts to "formalise the informal" and all the implications this has for the patterns of governance of informal sector activity. There are examples where linkages between the informal and formal sector have proved powerful; for example the Grammen Bank in Bangladesh is an informal sector banking arrangement backed by the formal sector banking system. However, in more technology centric domains of informal sector innovation it remains unclear how links can be productively built with the formal R&D sector. An on-going multi-country experiment by UNEP is using a challenge programme approach to identify social innovation emerging in the informal sector (for example waste management) and then acting as a scaling partner to diffuse these approaches more widely. While potentially valuable, it leaves unanswered questions about how this type of innovation capacity can be supported and about how benefits can be shared with innovators.

The review of the literature allowed for the visualisation of the different perspectives of the KS (see Figure 2 below) which proved to be hugely important as it provided a heuristic tool which facilitated discussions in each of the three countries, as described later. For brevity, it is not the intention here to explore the different perspectives on KS, Annex 1 provides the full conceptual literature review should more detail be required.

Figure 2: Different Perspectives on Knowledge Systems



A key reflection in the literature is the way the sphere of STI interest has progressively expanded in step with the broadening evolution of policy ambitions from science excellence to economic growth to sustainable development (Chataway & Daniels, 2020; Frost et.al, 2019; Schot & Steinmueller, 2018). We argue that it is the need to find ways to embed R&D in both the wider landscape of research commercialisation and societal needs - with all the implications this has for inclusion, transparency ownership of STI policy and practice - that points to the need for a different STI perspective. Emerging from the review of literature is the need to build a much more comprehensive picture of the STI environment than is possible with current framing. This needs to include:

- A recognition of a theory of change for STI investments that is mediated through systemic change processes across multiple scales from practice to policy across the whole of society, but at the same time recognises that the spread of component technologies and technology commercialisation play a critical role as part of the larger transformation process.
- A recognition of a diversity of sources and ways of organising innovation within and beyond the formal STI environment and an understanding of the way these relate to each other synergistically and antagonistically.
- Changes in the patterns of networks and collaborations needed to make use of a diversity of knowledge sources and support innovation ecosystem than deliver on development aspirations.
- The recognition of both market and non-market mediated pathways of innovation, for example the spread of new values and social innovations.
- A recognition of the importance of novel areas of innovation activity that could be become valuable ways of triggering wider transformational change processes.
- A recognition of the range of different impact measures of knowledge and innovation related activity; including economic growth, but also inclusiveness and sustainability measures.

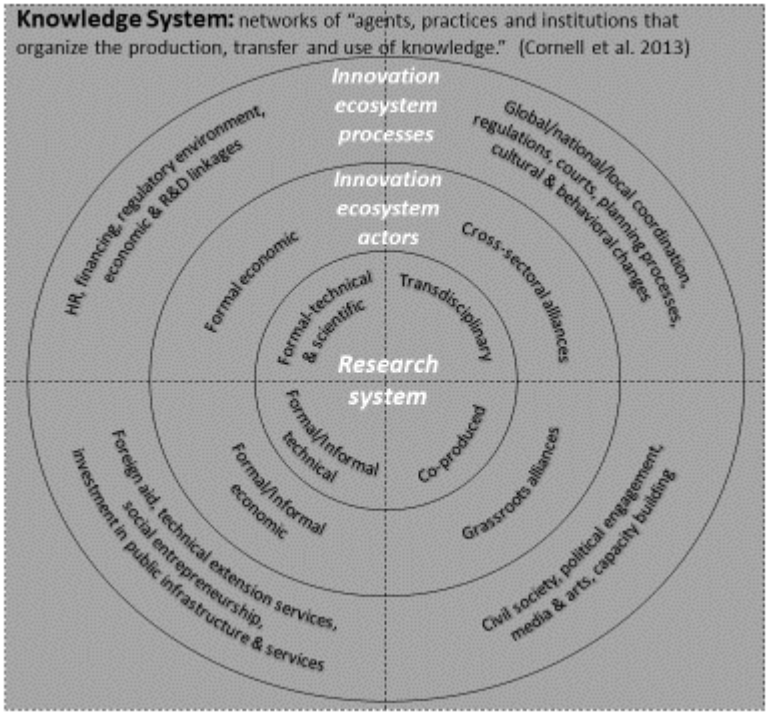
- A recognition of the role of patterns of stake-holding and governance in shaping the direction of innovation activity.
- A recognition of the respective roles of the State, the Market and civil society in ensuring the directionality of the innovation ecosystem.

Against this backdrop of the sustainable development agenda requiring transformational changes that involve complex challenges embedded across society and that have social, technological and political dimensions, this study proposes a practical conceptual framework, termed a **transformative knowledge systems perspective**. A transformative knowledge system is one that has a sufficient set of STI investments and capacities to drive the transformational change considered to achieve social development aspirations. For the purposes of this report we will simply refer to this as the ***KSI conceptual framework*.**

What does the KSI conceptual framework look like?

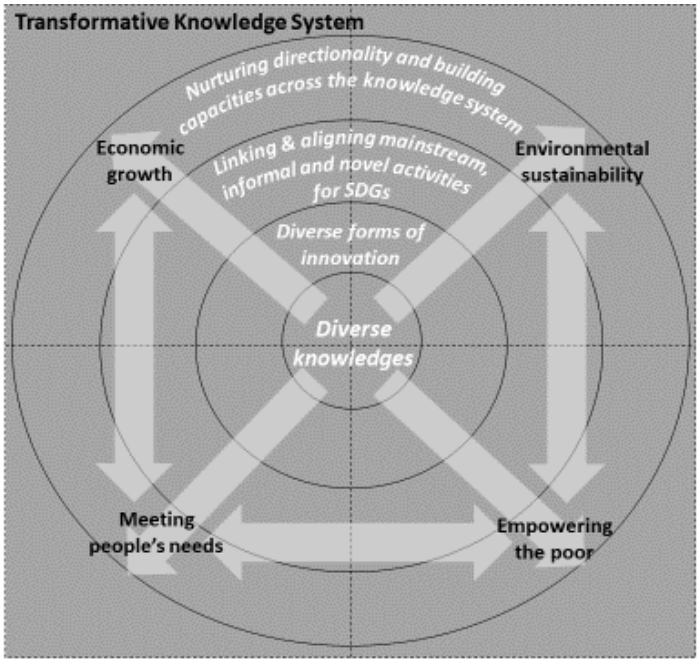
Building on the visualisation of different perspectives of KS from the literature (Figure 2 above), the KSI conceptual framework guides a process of characterisation (in particular country contexts) of the agents, practices and institutions involved in mainstream and emergent STI trajectories; supporting a mapping of interactions between the research system, the wider innovation ecosystem and diverse development outcomes (Figure 3).

Figure 3: Mapping of interactions between the research system, the wider innovation ecosystem and diverse developmental outcomes



It also directs attention to the potential for the development of a transformative knowledge system in which STI investment supports processes of transformation towards sustainability, and beneficial interactions between multiple STI trajectories support balanced growth needs. This is illustrated in Figure 4 below.

Figure 4: Illustration of a transformative knowledge system



It is appreciated that trying to describe a conceptual approach is challenging so Figure 5 below seeks to summarise the main aspects of the approach for STI investment for transformation that will need to be considered for the practical application. The KSI conceptual framework as developed and used by this pilot study demonstrates potential to deliver the more comprehensive understanding of the STI investments required to meet societal need in addressing the SDGs.

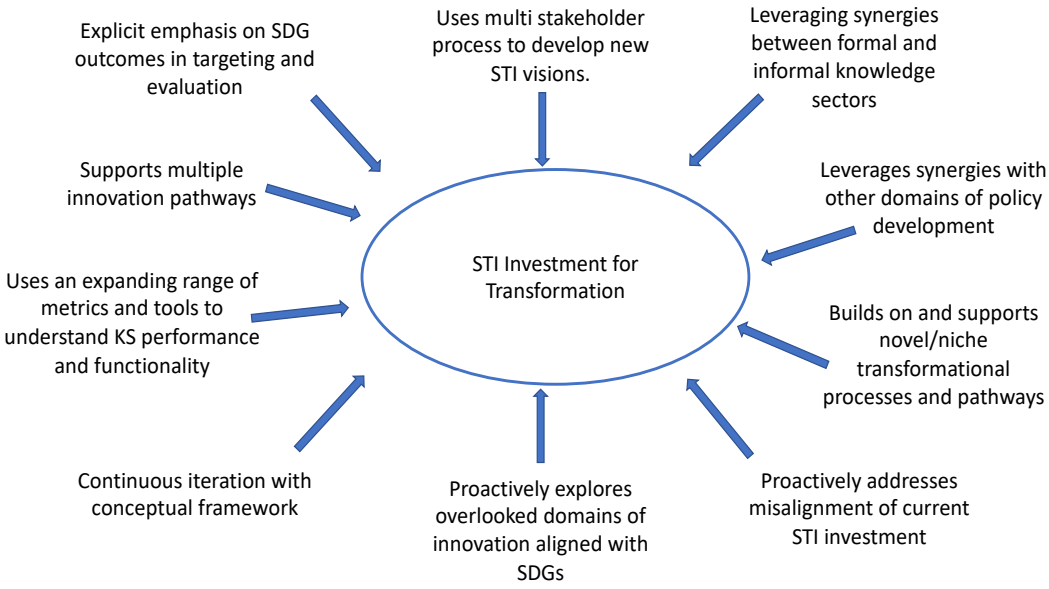


Figure 5: Some of the key aspects of STI investment for transformation that guide the KSI practical knowledge system concept

There are two practical insights that arise from the need to develop a more comprehensive picture of the STI ecosystem, both of which were implemented during this pilot study. Firstly, there is a need to use a range of different analytical diagnostic tools and perspectives to build and triangulate difference pieces of evidence from

across micro to macro scales and reveal different domains of knowledge and innovation related activities. Secondly, as the KSI conceptual framework is not a normative view of STI capacity there needs to be an embedded process of stakeholder engagement to ensure that new options are aligned with specific sustainable development challenges being faced in a particular country context.

The KSI conceptual framework outlined above also helps to highlight components of the KS that are currently neglected but are important in terms of STI being able to deliver more effectively for multiple SDGs and for the needs of diverse local actors. These components may be, for example, actors, conditions, technologies, institutions and governance arrangements that are configured in ways that will contribute to the building of a transformative KS. We recognise our KSI conceptual framework is a complement to other current initiatives which are concerned with STI policy and transformations to sustainability (e.g. UNCTAD (2019) and Chataway et al, (2017)). These initiatives are working towards the creation of national strategies for re-orientating innovation systems, and for setting up and monitoring of experimental policy mixes in order to achieve this. There is clear concern to make National Innovation Systems meet SDG agendas, but patchy availability of data to support recommendations for particular policy options, and limited attention so far on how policies which lead to particular types of STI investments link to the pursuit of the SDGs in particular contexts in practice. There is also momentum building up to begin to address these concerns, with several UN agencies, including UNDP and UNESCO are actively seeking to develop and foster policy approaches that direct science and innovation towards the SDGs. The KSI conceptual framework provides a context specific means of supporting the identification and prioritisation of context specific policy options with real potential to enhance SDG delivery. For brevity, further discussion of the conceptual framework is reserved for an academic paper which is currently in preparation with the intention to submit to Research Policy (in Autumn 2020).

The KSI conceptual framework is put into practice through a multi-stakeholder process – see Section 5 - (informed by primary and secondary data) which supports the identification of promising areas of KS activity and leverages them for systemic change.

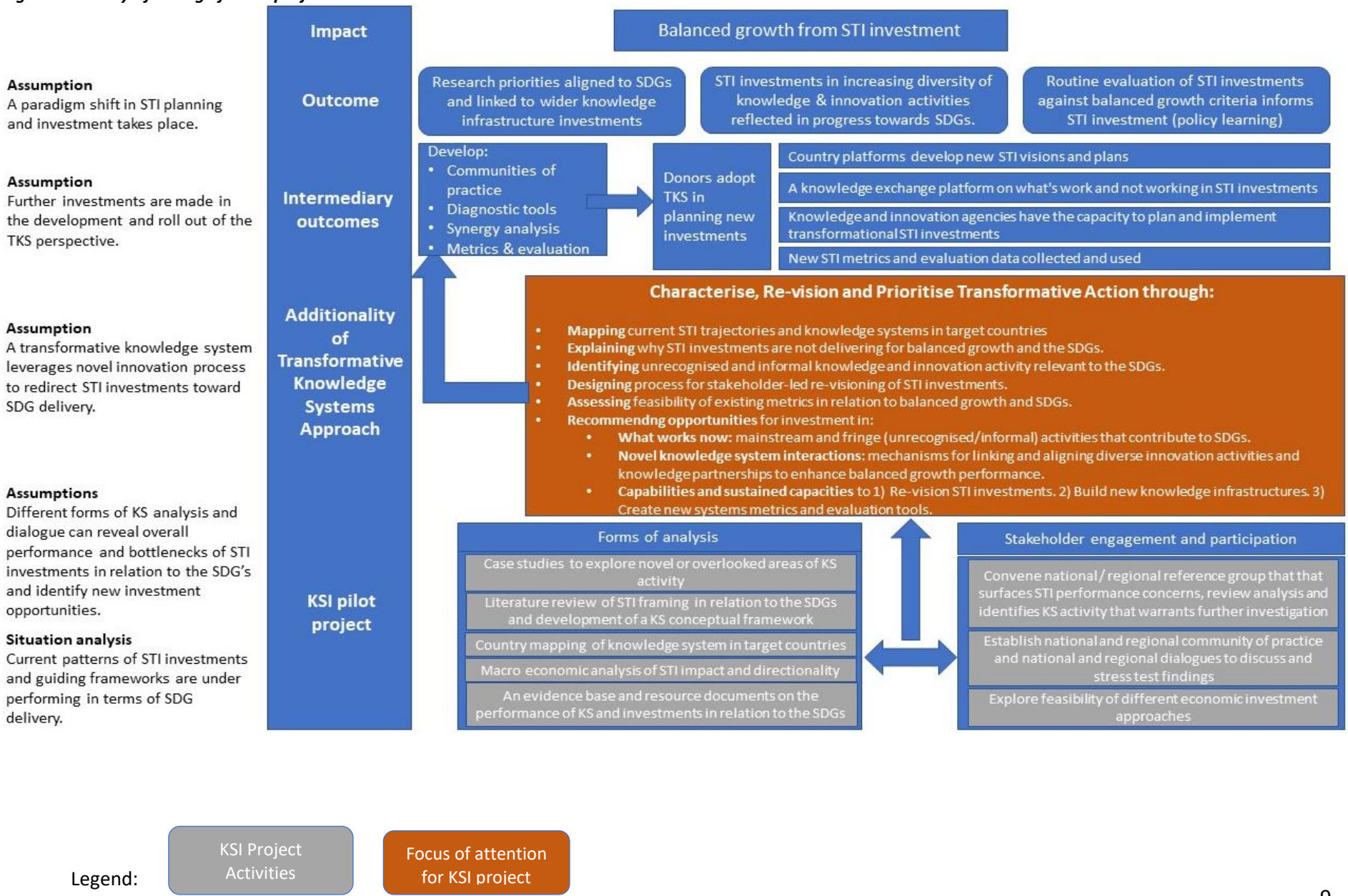
Section 3: Methodological approach

To facilitate the iteration between the development of the KSI conceptual framework outlined above and the use of this framework this study employed both quantitative and qualitative analytical methods (outlined below) to address lines of enquiry at three levels: macro (econometric data), meso (country mapping) and micro (case studies). These were employed to gather evidence, build communities of practice and reveal opportunities for investment strategies in support of balanced (or sustainable) growth. Together these contribute to the development of a new story about STI patterns and performance, and the basis of a guide for the identification of STI capabilities and capacity building priorities to support the translation to sustainable development pathways. The employment of these methodologies formed the foundation of the project level Theory of Change (ToC)[1] as presented in Figure 6 below. This study focussed on unpacking the ToC, particularly the central box shaded in orange, as we sought to define what was distinctive and novel about the proposed transformative KS approach as compared to more established analyses of STI investments i.e. what was the additionality of the conceptual approach developed by this study.

The KSI conceptual framework, in the sense that this study has developed and applied it, defines three linked areas of action: *Characterisation*; *Re-visioning*; and *Prioritising transformational action*. As a pilot study considerable attention has been focussed upon the former, the characterisation of the KS (see section 3.1 below) but also on revisioning and prioritisation, through the in-country engagements (see section 3.2 below). For example, the discussions on the different perspectives of KS (Figure 2 above) began to establish/envision what sort of KS would be desirable and the country Community of Practice (CoP – see below) takes this forward through the more detailed characterisation process. This approach also saw types of transformative actions beginning to emerge also. Building on the social capital developed by this pilot project is one of the recommendations later in the report (see section 7).

[1] The original TORS tasked this pilot study to prepare a ToC for each of the three countries – this was clearly going to be a highly ambitious objective within the timeframe. It was agreed with FCDOduring the Inception Phase that the study would only prepare a project level ToC.

Figure 6: Theory of Change for KSI project



The following section briefly outlines the forms of analysis and the multi-stakeholder engagements (shown in the silver boxes at the lower level of the ToC in Figure 6) employed to demonstrate the practical application of the concept proposed. The purpose of these are discussed below along with brief details of how this was applied in practice in this study.

3.1 How did we characterise the knowledge system?

The purpose of this action was to generate information and analysis on current patterns and impact of knowledge related activity. This involved the following lines of enquiry:

(i) **Mapping and diagnosis:** What are the existing patterns of knowledge actors, functions and resources, the interconnections between these and the diversity of participation in knowledge related activity?
(ii) **Directionality and impact:** Analysis of the targeting of existing STI investments. What is the impact of STI investments, alignment with SDGs and other development priorities and with the aspirations of different stakeholder groups? What are the drivers, enablers and barriers that shape and reinforce current STI trajectories?
(iii) **Opportunities:** searching for novel innovation activity that has the potential to contribute to the SDG agenda and the identification of capacity building and other resources needed to support this.

The specific research activities that were undertaken to address the three lines of enquiry are outlined below, each had limitations which are also testament to the challenges this study faced.

Econometric work
It has already been mentioned that this work was undertaken accepting that there are huge methodological challenge in linking STI investments to social outcomes and impact. This study approached this challenge from different angles through three empirical exercises conducted to measure different aspects or proxies of the knowledge environment in Kenya, Rwanda and Tanzania and study their relationship with socio-economic outcomes. Based on the literature and the conceptualisation of the KS approach the project has defined and characterised seven components (or proxies for elements) of the knowledge environment that help translate research into impact – these are **education and human capital**; **government Science and Technology (S&T) support and policy**; **infrastructures**; **markets and trade**; **regulation and governance**; **socio-political institutions**; and **technological capabilities**. Most of these seven proxies cannot be measured with available macro data highlighting the methodological challenge.

First, we used 74 publicly available country level variables to measure different components of the KS and study how the three countries, perform with respect to the different components in relation to all LMICs. Second, we study the dynamic relationships of the KS components and economic development in LMICs. Third, we study the relation between one particular component of the KS, the research system, with different development outcomes, the SDGs, in the three countries.

This sought to address three main questions, namely:

(1) **What are the strengths and weaknesses of KS in the three countries?** How do the three countries score on the measurable aspects of the knowledge environment with respect to the rest of LMICs?
(2) Are different measurable aspects of the KS equally beneficial to economic development? How does this change for different levels of economic development and strength of the KS? **What is the dynamic relationships of the KS and economic development?**
(3) On which topics/areas is research investment prioritised in the three countries and to what extent is the distribution of research topics related to their SDGs target indicators? **Recommendation for the economics investment case?**

Section 4 below provides our work in finding answers to these questions, and aimed to provide guidance on (1) which components of the KS may need improvement in each of the three countries; (2) which aspects of KS

needs to be prioritised to achieve economic development; and (3) how investment in the research system may need to be rebalanced to contribute to SDG targets.[2]

Country level reviews
Based on initial in-country consultations to understand current STI environments and priorities, country level reviews were undertaken. These were based on reviews of secondary literature, previous policy reviews and evaluation, and where available, project reports. Each report focused on the follows set of issues that then formed the template for each country review report:

- An overview of the current STI environment, including its governance arrangements;
- Examples of existing types of innovation strengthening interventions;
- Emerging opportunities for leveraging STI investment for the sustainable development agenda;
- Evidence of sustainable development impact.

Case studies
The micro-level analysis aimed to provide a better understanding of the opportunities and challenges within individual country contexts for delivering for sustainable growth. Initially, nine case studies were selected with the country teams, but resources dictated that six case studies (two per country) would be undertaken; this was an obvious limitation to the study. Case studies were selected on two criteria that emerged from the country reviews. Firstly, exploring initiatives that were seeking to address some of the generic STI challenges identified, particularly the research uptake challenge. Second, allowing a more in-depth look at promising fringe knowledge and innovation activities, particularly in the informal sector. In all cases, particular attention was paid to partnership arrangements between KS actors and initiatives, and to the barriers and enablers that influence effective and sustained contribution to development goals. The portfolio of case studies undertaken were as follows and these are discussed in more detail in Section 5.3.2 below:

Kenya

1. Mechanisms for linking academia with industry in different university settings: Industry-university partnership practice in Strathmore and Jomo Kenyatta University of Agriculture and Technology
2. *Utafiti Sera:* a platform for research evidence into policy use and uptake.

Rwanda

1. Cases of bridging indigenous knowledge with sustainable development and inclusive health systems: *''the case of medicinal plants research and engaging traditional healers''*
2. Understanding the impact of investments in the development of innovation hubs and centres towards SDGs: *''the case of k-lab and Fab-lab incubation centres''*

Tanzania

1. The impacts of innovations in the context of KS: The case of Buni Innovation Hubs versus Tanzania Vocational Education Training Authority (VETA) Programmes
2. Institutional innovations in agricultural technology outreach: Case of Sokoine University of Agriculture' Village Knowledge Centres.

3.2 Going beyond characterisation

Given the very nature of the research and the objective to develop a practical KS concept for ***characterising*** the KS in the three countries it is unsurprising that the characterisation work formed the substantial component of the activities undertaken during this pilot study. However, it is important to emphasise, as we have attempted to present within the do ToC above, that characterisation of the system alone is insufficient and there needs to be further stages in terms of re-visioning and prioritising transformative action (which are briefly outlined below). This study also undertook a number of precursor steps to facilitate the next stages which involved a continuous and open discussion process in each of the three countries which is also described below in forming a CoP. We will return to the CoP in the recommendations as there is an opportunity to capitalise upon the social capital that this study has generated.

[2] Please note that SDG targets were used in this work because they provide a shared measure of socio-economic outcomes. As for the KS components (inputs), the choice of outputs is driven by data availability, which may not coincide with what should be prioritised.

- **Re-Visioning -** the purpose of this action would be to engage policy and other development stakeholders in a re-visioning of STI investments, asking questions about the types of balance growth objectives that STI investments seek to deliver, explores how STI arrangements would need to change to achieves this. The process uses evidence and analysis developed in the characterisation work to highlight mismatches between aspiration and current STI policy and practice and performance. The end point of the re-visioning process is a prioritisation of STI investments to support the transformational KS needed to meet the SDG agenda.

- **Prioritising transformational action –** the purpose of this action would be to use the evidence from the characterisation work on novel areas of innovation activity to select and design new investment options that build on identified opportunities. This involves both consultation with policy and other development stakeholders, but it may also involve further targeted analysis and feasibility studies to inform programme design and resourcing.

3.3 Process for in-country dialogue and engagement

From the outset of the study we fully appreciated the need for a continuous open dialogue within the three countries as we sought to test the feasibility of developing and applying a KS approach to the STI context in the three countries and to stimulate and engage in wider epistemological debates. Over the course of the study the following engagement processes were undertaken in each country which supported the development of a CoP, a precursor step for re-visioning and realisation of transformative potential. Our study had three country teams based in a leading university namely the Universities of Nairobi, Dar es Salaam and Rwanda respectively. Our approach also had ACTS as a convening partner operating across the three countries which was a vital linkage to enhance lesson learning but also to navigate through quite a challenging conceptual process given the three countries were found to be at very different stages of their STI policy development. In each country, we created a National Advisory Committee designed to challenge the KSI project team and to provide representation from the country into a Regional Advisory Group. We found that both structures were invaluable as the project attempted to iterate between design of a practical KS concept and the implementation of such a concept in the three countries. The TORS and membership of the three National Advisory Committees and the Regional Advisory Group are provided in Annex 2.

In terms of events and meetings, in each country we held:

- An inception meeting which had the purpose of introducing the project and take their guidance on the way in which the characterisation process could be implemented. These meetings provided fundamental insights in the current STI landscapes within each country and allowed us to broaden the network of relevant country stakeholders.

- A validation workshops which followed the meso-level analysis of the country level reviews with the purpose of ground truthing and helping identify promising fringes and issues that had not yet been covered by the country reviews.

- Focus group discussions which had a greater emphasis on drivers and delivery pathways in order to support the selection of the case studies (our micro level analysis) for more in depth investigation.

In addition to the country level events we held:

- Two Regional Advisory Group meetings to develop ownership, seek recommendations, build bridges in wider policy forums.

And finally, we held a meeting to bring together all regional stakeholders to share the results from the characterisation work (and the different insights from the different levels of analysis) and to undertake some of the above-mentioned precursor steps namely:

- to start of a process of co-learning about STI for what and for whom? (addressing the directionality question, the diversity of forms of knowledge and innovation and distribution of benefits);
- to start of a process to consider the need for a different STI narrative;
- to start to build recognition around the commonalities of challenges about STI investment and;
- to start shared learning regarding the types of transformative potential that can be explored through case studies.

Our novel approach designed and employed during this pilot study was an enabling process that allowed the project to introduce a different conceptual framing, for it to be ground-truthed and challenged by the structures we established in each country and to set a foundation from which to build, in allowing for stakeholder-led re-visioning of the patterns of STI investments after this project had concluded (see section 5.4 below).

The engagement processes outlined above proved to be very successful and provided a genuine forum for discussion. This approach was well received and appreciated with the country teams taking ownership. The success was undoubtably aided by the ready appetite for the discussion that this project brought to the table and there was a clear momentum for thinking differently. Another striking observation from the engagement process was the number of potential case studies that were proposed during discussions. It has already been noted that resources only allowed for 6 case studies in total but there were many, many more that could have been examined had resources permitted. This provides evidence not only of the number but also the great interest there is in these exciting fringe innovation activities that are clearly happening within the three countries under study. As such these activities are currently outside the mainstream of current thinking and indeed analysis; this will be an issue we will revisit in Section 7 in terms of recommendations in going forward.

Referenced has been made already that the conceptual approach was challenging given the different trajectories of the STI policy landscapes within the three countries. One noteworthy aid albeit not originally planned was the use of conceptual diagram of the different perspectives on KS developed during the literature review (as presented Figure 1 above). The project team were somewhat wary of introducing this into discussion in case it caused confusion. To the contrary, this diagram provided a heuristic tool to give the conceptual approach some tangibility, a focal point that enhanced discussions in all three countries, to develop a deeper understanding of existing STI patterns and practices which are discussed in more detail in Section 5 below on the three individual countries.

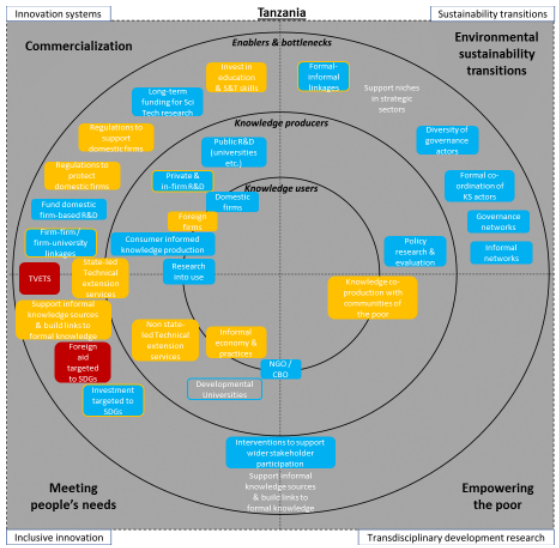
A conceptual framework that emphasizes (i) **diversity of knowledge sources and innovation domains,** (ii) uses purposeful **alignment to the SDG agenda as a key performance indicator** and (iii) **explores the potential of novel forms of knowledge and innovation activity to disrupt and transform the STI environment towards a more transformational direction**

It was never the intention of the study to make direct comparisons across the three countries given there are significant country to country differences in terms of where they are currently in terms of STI policy development, implementation and directionality. The purpose of presenting the figures here is purely to highlight the differences between the three countries and the benefit of the in-country engagements undertaken by this study. Figure 7 below presents the dimensions of KS for each country as derived from literature reviews and then again after ground-truthing discussions in each country. Again for brevity, it is not the intention to describe in detail as key aspects will be picked up within Section 5 below – suffice to say the STI context in Rwanda takes a state-led approach to innovation systems directed to economic and sustainable development goals. In Kenya, the STI context centres on improving and expanding basic and higher education and in Tanzania, where the STI context is currently weakest of the three countries under study, where the STI context is focussed around the alleviation of poverty.

Figure 7 Comparison of the dimensions of the knowledge systems in Kenya, Tanzania and Rwanda before and after stakeholder discussions

Before in-country discussions

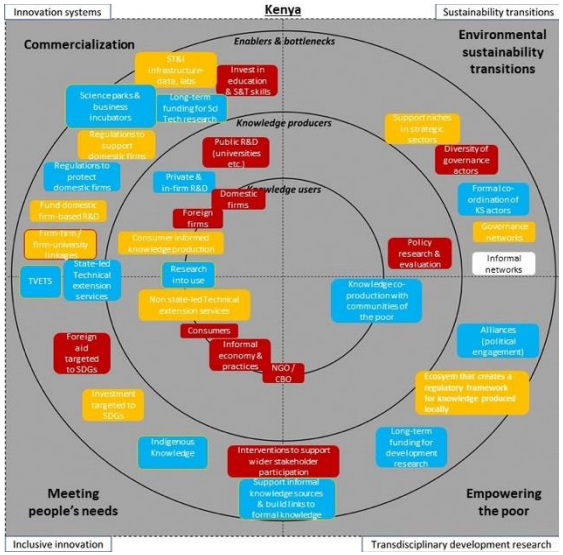
Kenya

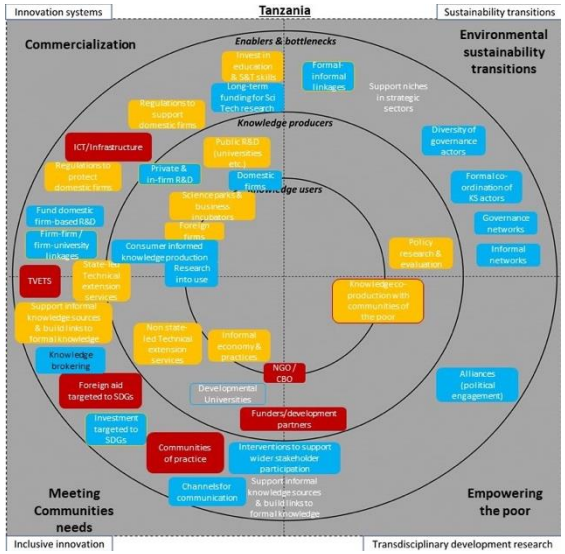


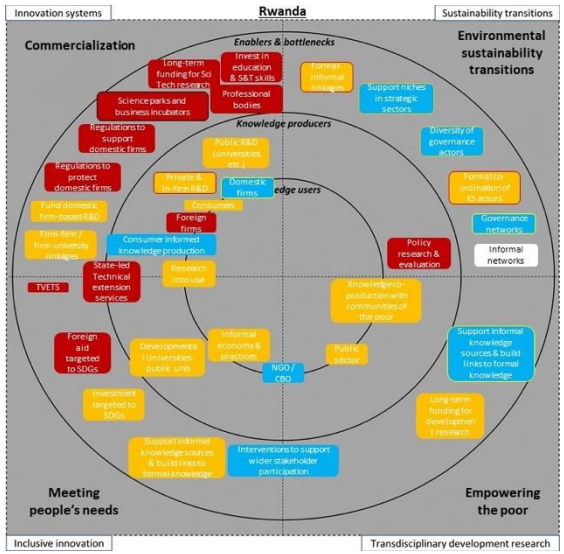
Tanzania

Rwanda

After in-country discussions







Strong and well established KS components

Emergent KS components

Weak neglected KS component (but improving)

Weak KS component in decline

Section 4: What does an economics approach tell us about impact and alignment of investments in Kenya, Tanzania and Rwanda?

The second study question sought to develop an economics approach that can identify the impact and alignment of the investments in the target countries and to identify the feasibility considerations and limitations. In addressing the challenge it is important to put this study in the context of current literature.

4.1 Introduction to the economic evaluation of innovation

Much of the literature investigating the returns to investment in STI focuses on R&D investment. Both micro (e.g. Griliches, 1979; Jones and William 1998; Hall et al., 2010) and macro (e.g. Salter and Martin, 2001; Haskel and Wallis 2013) studies rely on production function estimation where output of a firm (for micro) or an economy (for macro) is related with its stock of R&D or intangible knowledge capital. This framework relies on a number of assumptions that are subject to criticism in advanced economies, where R&D is a major source of innovation. These criticism become more relevant in countries where R&D is a less relevant component of the innovation efforts. See for instance a recent paper by Hall (2020) on the use of patents to measure innovation in LMICs. The process by which STI can positively affect economic growth is complex, let alone how it affects other societal challenges. The problem is made more complex by the well-known evidence that innovation does not occur as a linear process (Kline and Rosenberg, 1986) Freeman, 1987; Lundvall, 1992; Nelson, 1993). It is even more complex if we consider countries in which knowledge is produced both formally and informally, and both are difficult to capture in the data. We therefore face an issue with respect to measuring KS inputs (the "investment"). In this study we opted for a less critical assumption on what may contribute to creating and using knowledge that may lead to an improvement in socio economic wellbeing. As Gault and others explain, the history of data collection and evolution of STI indicators to inform policy development is closely aligned to debates about how research, innovation and, increasingly, broader development, happens (Gault, 2013); and how STI indicators do and should inform policy.

The evolution of data collection from the Frascati (OECD, 2015) to Oslo (OECD, 2005) to Bogota (RICYT, 2001) manuals reflects changes in understanding how knowledge is created and how it contributes to society. As discussed by Rafols, Stirling, Ciarli and colleagues (Stirling, 2008; Rafols et al., 2012; Ciarli, Coad, and Rafols, 2013), the choice of indicators may be political, influence results, and limit policies and decision making to narrow development pathways. To better inform policy makers and civil society about plural development pathways (Stirling, 2009), it is crucial to complement and compare different indicators, which are informative on different aspects of the KS. To deal with this complexity we combined macro data, to study different components of the KS, well beyond the restricted view of R&D. However, we could only scratch the surface, as a lot more work needs to be put in improving how the KS inputs are measured. To be sure, the measured components of the KS represent only a small subset of all components and actors that generate and use knowledge in a system.

Study question 2

Can we develop an economics approach that can identify the impact and alignment of the investments in the target countries and what are the feasibility considerations and limitations of this work?

This study identifies alignment challenges but critical limitation in data and methods tell a compelling impact story associated with policy implementation.

Our work provides a statistical understanding of the strengths and weaknesses of the different measurable components of the KS in different country contexts.

Our work provides an improved understanding of how these components relate to each other dynamically (synergies and trade-offs) and how they influence outcomes long-term.

Together these points provide better understanding of potential biases in resource allocations in research systems.

Our analysis sheds some light BUT the results need careful interpretation. The analysis can be done but needs to be undertaken in conjunction with other types of analyses to help policy makers with their decision making.

Aside from the choice of KS aspects, there are well-known challenges with data measurement and reporting in LMICs (Jerven, 2013). Moreover, the current state of the art in data collection on investment in STI, in high income countries, has been subject to extensive discussion and critique (Eurito, 2018). There is growing agreement that new approaches are needed but little consensus on what is needed or what is possible. While integrating different aspects of the KS provides a more complete picture of the complex relations that lead to innovation, estimating returns to investment of KS components, such as education or technological capabilities may be problematic because these cannot be represented as simple inputs of a production function. For example, number of pupils attending a given school level, and number of engineers in the population are not the result of a one-off investments.

The estimation of how different aspects of the knowledge environment are related dynamically, is also subject to a crucial bias: analysis may be omitting components of the KS that are more relevant than those measurable with available data, and/or that interact in complex ways with those measured, which may alter substantially the results. Our results presented in the next section refer to average relations, and do not speak to how the observed outcomes may differ across sub-national geographies and demographics. Macro data sets, such as the one used here, need to be complemented with case studies and triangulation between different types of micro data, including qualitative data. Overall, the evidence provided should be used as a guiding map that Governments and donors like FCDO may use to make investment choices over a wide-ranging portfolio, rather than as precise indication defining RoI on specific aspects of the KS. Based on our analysis we can make several recommendations for taking STI investment work forward; these are presented in Section 7 below. In addition to this final technical report, a separate annex on making the economics investment case was presented to FCDO previously and three academic papers are currently in preparation for submission:

- Measuring knowledge systems in Kenya, Rwanda and Tanzania versus other low and middle-income countries;
- Knowledge system and economic development: A panel VAR analysis of low and middle-income countries;
- Mapping scientific systems in Kenya, Rwanda and Tanzania and its relation with Sustainable Development Goals (this draft paper is presented in Annex 3).

The following section presents our broad macro analysis for the development of an economics approach that can identify the impact and alignment of STI investments in the target countries. It also addresses feasibility considerations and limitations of this work. It has been a conscious decision to present the broad macro analysis separately to demonstrate the differences and the added value of the practical application of the KSI conceptual framework.

4.2 What are the strengths and weaknesses of the KS in the three countries

As outlined in the methodology above, our analysis combined a subset of 74 publicly available country-level macro variables (for which data is available) for 121 LMICs from 2007 to 2016. Each variable was assigned to one of the seven proxies e.g. the education and human capital proxy is measured using 11 variables: quality of the education system, of primary schools, of STEMS, and of management schools; internet access to schools; pupils/teacher ratio in primary schools; enrolment in primary and tertiary schools; number of teacher in secondary schools; completion rate of primary schools; and duration of compulsory education. These different variables cover aspect such as quantity of education, as well as quality, infrastructures, and investment.

Based on the literature and the conceptualisation of the KS approach the project has defined and characterised seven proxies for elements of the knowledge environment that help translate research into impact – these are **education and human capital**; **government Science and Technology (S&T) support and policy**; **infrastructures**; **markets and trade**; **regulation and governance**; **socio-political institutions**; and **technological capabilities**.

Factor analysis was then used to determine the variables with the strongest correlation to the seven proxies as follows:

- Education and human capital: quality of schools; investment in education and school attendance
- Government S&T support and policy: industrial policy; investment in scientific and technological capabilities

- Infrastructures: ICT and access to electricity; quality of infrastructures
- Markets and trade: final demand, including access to cash; international trade; financial services; burden to do business
- Regulation and governance: Legal framework; contract enforcement
- Socio-political institutions: strength of institutions and the rule of law; social capital
- Technological capabilities: Technology transfer and innovation capabilities; technological capabilities;[3] capacity to attract talents

Unfortunately, data series on the level of R&D expenditures, such as Gross Domestic Expenditure on Research and Development (GERD), was not available for many LMIC, most SSA countries, including Kenya and Rwanda. Not to mention data at lower level of aggregation. However, a number of variables reflect expenditure in different components of the knowledge system, such as education spending (Education and human capital), government procurement and university-industry collaborations (Government S&T support); ICT infrastructures; foreign direct investments (Markets and trade); and innovation outputs such as patents (Technological capabilities).

The analysis highlights key difference between Kenya, Rwanda and Tanzania which are summarised in Table 1 below. **Kenya** is in a relatively **strong position** (among the top 20% LMICs) with respect to other LMICs particularly in crucial aspects such as **government S&T support and policy** (e.g. government procurement and direct investment in research (industrial policy) and research inputs and outputs); **regulation and governance** (e.g. efficiency of legal system and property rights procedures); and **technological capabilities** (e.g. transfer through FDI, absorption of technologies, management (innovation capabilities), patenting and specialisation in higher technology goods (technological capabilities) and capacity to attract and retain talents). These should be regarded as leverages for future development, although there is space to improve weaker aspects of the knowledge environment such as education, infrastructures, and socio-political institutions (where Kenya scores among the top 40% LMIC) and especially markets and trade (where Kenya scores in the middle of the distribution among all LMICs).

Tanzania's strengths (among the top 20% LMIC) lie in **regulation and governance** (e.g. efficiency of legal system and property rights procedures) and in **government S&T support and policy** (e.g. government procurement and direct investment in research (industrial policy) and research inputs and outputs). But would benefit from improving all other components of the KS, especially education, infrastructures and markets (where Tanzania scores among the lowest 40% LMICs), as well as socio-political institutions (where Tanzania comes among the top 40% of LMIC) and technological capabilities (among the average) including those related to the private sector and developing technological and innovation capabilities.

Rwanda does not perform well in most of the aspects analysed. According to our analysis and variables used here, less problematic are socio-political institutions and regulation and governance (where Rwanda scores among the top 40% of LMICs) and government S&T support and policy (average). Where the country may need to improve substantially, in relation to other LMICs, is with respect to education, infrastructures, markets and technological capabilities, where the country scores among the bottom 40% of the LMICs.

Table 1. Performance of the KS in Kenya, Tanzania and Rwanda in relation to LMICs.

Country	Education score	Govt S&T support score	Infrastructures score	Market score	Regulation score	Institution score	Tech capabilities score
Kenya	Top 40%	Top 20%	Top 40%	Average	Top 20%	Top 40%	Top 20%
Tanzania	Bottom 40%	Top 20%	Bottom 40%	Bottom 40%	Top 20%	Top 40%	Average
Rwanda	Bottom 40%	Average	Bottom 40%	Bottom 40%	Top 40%	Top 40%	Bottom 40%

Based on their relative performance with respect to the seven proxies of the knowledge environment, countries can be clustered into five groups (Figure 8 below). Cluster 5 (brown) consists of 31 relatively large economies

[3] For a distinction between innovation and technological capabilities please see Bell and Pavitt (1993).

ranking highest with respect to five of the seven proxies (government S&T support and policy; markets and trade; regulation and governance; socio-political institutions; and technological capabilities). Remarkably, education and human capital and infrastructures do not feature highly in those countries (such as in Kenya). Cluster 3 (green) is populated by countries ranking highest in terms of education and infrastructure, and relatively high in all other components, except with regulation and governance. Cluster 2 features countries above average with respect to regulation and governance, but below average in terms of education, infrastructure, markets and technological capabilities. Countries in Cluster 4 perform below average with respect to most proxies, except education and markets. Cluster 1 is composed of the least performing countries across all of the seven proxies. While **Kenya** fits into the highest-ranking cluster along with dominant large economies including China, India, South Africa and Brazil. **Tanzania** and **Rwanda** fall within cluster 2.

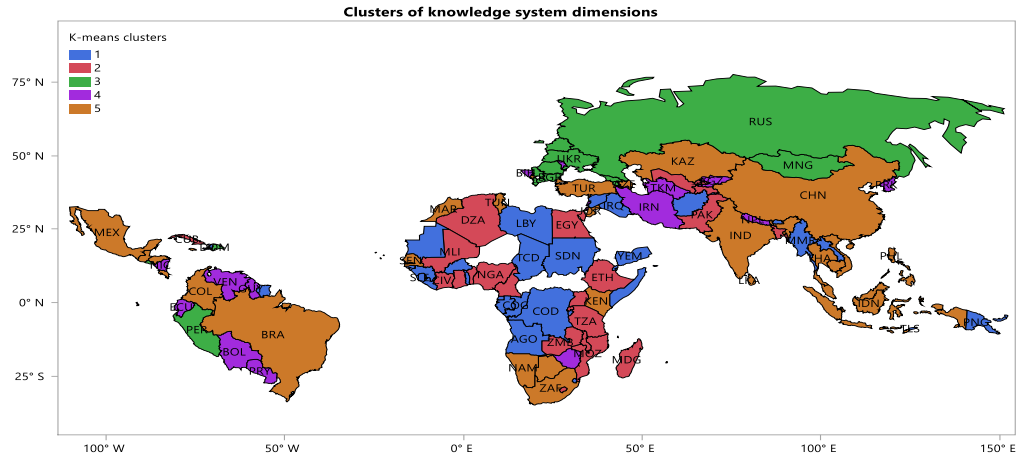


Figure 8: Cluster of countries with respect to their ranking of KS strength

4.3 What are the dynamic relationships of the KS and economic development?

Having studied the strength and weaknesses of the three countries across the measurable elements of the KS, the project then analysed how these relate to each other and to socio-economic outcomes. Evidence of causal relations between components may allow policy makers to exploit synergies and trade-offs between them, for instance where weaker ones may benefit from stronger ones. We estimated the dynamic causal relations between four of the seven proxies and economic development (GDP) between 1990-2016, in over 118 LMICs using panel vector autoregressions (Love and Zicchino, 2006). When going back to 1990, due to data limitations, we have to focus on a more limited number of KS proxies (four), each measured against fewer variables (12 in total). This allows us to improve the identification of the causal relations, at the cost of losing precision with which the components are measured. Given the three countries pertain to different clusters, we also tested these dynamic relations for groups of countries, differing by economic development and KS strength.

The factor analysis over the 12 available returns four factors, each of which is one of the seven proxies adopted by this project:

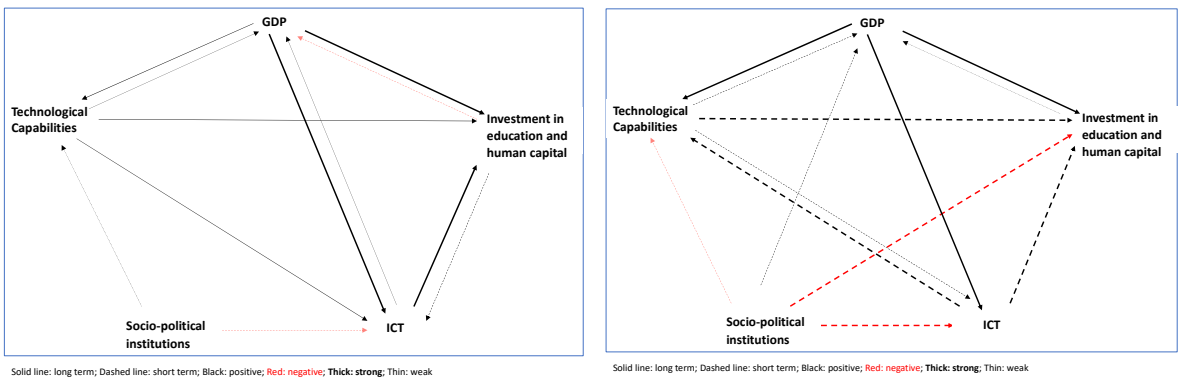
- Education and human capital, composed by the following variables: number of secondary school teachers, primary school enrolment and completion rate, tertiary school enrolment, and number of scientific publications
- ICT infrastructures and use, composed by the following variables: number of internet users, and mobile phone subscriptions
- Socio-political institutions, composed by the following variables: civil liberties and political rights
- Technological capabilities, composed by the following variables: number of patent applications, share of value added from medium and high tech sectors, and high tech exports

Results (not reproduced here) show that ICT and technological capabilities have the strongest and long lasting (decade-long) impact on GDP, followed by a short term impact of socio-political institutions. It is, however, important to remember that these are proxies: the impact of ICT infrastructure and use is measured as an increase in the number of internet users and mobile subscriptions and, the impact of technological capabilities is measured as an increase in the number of patent applications, the share of medium-high tech in terms of total

value added and the share of high-tech in total exports. It is also important to note that GDP has an even stronger impact on technological capabilities and ICT infrastructures. That it, economic growth seems to be a condition for investment in technological capabilities and ICT, which will then spur further growth. Rather than the other way round.

Education and human capital also benefit from technological capabilities and ICT, but mostly from GDP. But does not appear to provide pay-back: the education proxy has no positive impact on other proxies, or GDP. This is in line with the literature that suggests that it is the quality, rather than the quantity of education that matters. However, this may also be due to problems in reporting education data across different LMICs. We also note that, while socio-political institutions (civil liberties and political rights) have a positive impact on GDP, they have a smaller negative, short-term, impact on both ICT infrastructure and education. This result is likely to be driven by countries that have invested strongly in infrastructures and education, while limiting civil liberties and political rights.[4] As noted above, the three countries under study pertain to groups of countries performing differently with respect to the aspects of the KS. We explored how these causal relations change for countries differing by strength of the KS. When distinguishing by KS strength the main results discussed above hold for countries with a strong KS, such as Kenya (see Figure 9 below). There are two important differences though: first, socio-political institutions have a positive impact on technological capabilities, rather than directly on GDP, and have no negative impact on education; second we find a small, short-term, negative impact of education and human capital on GDP, suggesting that overspending in education may not pay-back, if the education workforce is not absorbed by the labour market, causing a brain drain.

The causal relations differ substantially when we move to countries with a weak KS, such as Rwanda and Tanzania (Figure 9 below). First, technological capabilities and ICT infrastructures have a lower, short-term impact on GDP whereas, both socio-political institutions and education have a positive impact on GDP. There appears to be a virtuous cycle in weaker KS contexts that can be exploited. In the short-term technological capabilities and ICT have a strong positive impact on the education and education has a positive impact on GDP. GDP has a long germ impact on technological capabilities and ICT, which feedback on education, and so on. Moreover, technological capabilities and ICT infrastructures feedback on each other. Second, and more worryingly, weak KS institutions have a negative short-term impact on all other KS components (although they still impact positively on GDP). This may be interpreted in the light that stronger regimes were able to invest more in all KS components, or that as countries become more democratic, there is a short period of institutional adjustment which does not benefit KS components in the short run.



Strong KS Weak KS

Figure 9: Dynamic causal relations between KS and GDP: strong and weak KS contexts

4.4 Recommendation on the investment case on different components of the KS

Taken together, results suggest the following recommendations for **Kenya**, which is weaker with respect to the KS proxies of education, infrastructures and institutions: i) stronger institutions may have a stronger positive long term impact on technological capabilities, which are a crucial driver of economic growth; ii) stronger ICT infrastructures than currently available may have a positive long term impact both on economic growth and on education; iii) the education system also needs improvement, but its impact on economic growth crucially

[4] We find that this negative impact is present only in lower income countries. In high income countries socio-political institutions have a positive impact on education investment and outcomes.

depends on the quality of education and on the capacity of the Kenyan labour market to absorb high qualified workers.

Rwanda and Tanzania start from a weaker KS base: i) first, both would benefit from investing in technological capabilities, although these are also conditional to higher GDP; ii) ICT infrastructures are likely to play a strong role in both improving technological capabilities, and the education system, which in turn have a positive impact on GDP. Both countries would strongly benefit from investing in quality education.

4.5 Mapping the relation between the research system and the SDGs

Domestic research plays an important role in creating the capabilities (Gibbons et al, 1994; Wallace and Rafols, 2015), within all three countries, to enhance their achievements across the SDGs, beyond GDP. The project mapped the research investment across topics in the three countries from 1990-2017 and the collaboration networks between research organisations in each country, and then analysed how research priorities have been aligned with the SDGs. The central assumption is that a misalignment between investment in research areas and the SDGs may reduce the effectiveness of the investments in research to address those challenges (for a start because research capabilities are not created to address those challenges).

Bibliometric analysis, used as a proxy for research investment, highlights the misalignment of patterns of publications and the SDG agenda. It has also revealed the way this pattern of publication is skewed by collaboration (and funding) with organisations in the global North.

Because no data is available on research investment disaggregated by recipient and source, we used scientific publication as a proxy for research investment. Ciarli and Ràfols, (2019) provide some evidence, for countries with detailed data such as the US, that the relative amount of funding is highly correlated to the relative amount of scientific publications, by topic. To proxy for the source we use the acknowledgment paratext in the publications, as is common in the literature. Again, this is a proxy because not all publications include the funders in their acknowledgment. Finally, to measure socio-economic challenges we used the SDGs indicators from the SDG index. This analysis connected research investment and SDGs by searching a combination of keywords related to each SDG in scientific publications. Our work first mapped the research systems of the three countries and identified how the investment was distributed across different research areas and topics. Second, the analysis assessed the association between investment in research on SDGs and SDGs achievements. Third, the project analysed how different funders contribute to the above research outputs (according to funding acknowledgements in publications, see Annex 3 for more detail). Findings from this type of analysis may allow policy makers to redesign investments in knowledge in the research system, in relation to the SDGs.

As noted above, the government S&T support and policy aspects of the KS, which includes investment in scientific and technological capabilities, is relatively stronger in both Kenya and Tanzania. This is confirmed by mapping the research system of the three countries (Figure 10 below). Although in all three countries research is concentrated in few institutions[5] Kenya and Tanzania have a denser network of research organisations that publish consistently. Common to the three countries is that the main research collaborators of all the top research organisations are not national but international (mostly from the USA and UK). Given the relevance of research in building local capabilities to address SDGs, it is important to better understand how such collaborations may be shaping the national research prioritisation, in relation to the SDGs, and therefore building such capabilities in the research system.

Research prioritisation: Semantic analysis of research outputs (scientific publications) from the three countries show that in all countries there is a strong focus on topics related to health (e.g. tropical medicine, parasitology, infectious diseases, maternal health) and agricultural sciences (e.g. grain and maize yields, pests, cattle). In general, there seems to exist an absence of research investment in engineering and physical sciences, which may contribute to develop the technological capabilities, which were found above to have an important role in economic growth. When we allocate these research outputs to the 17 SDGs, we find that all three countries' research investment (proxied by scientific publications) is mainly focussed on SDG3 ("Good health and well-being") – between 44-56% of total publications. This is despite the importance other SDG's in these countries

[5] University of Nairobi and KEMRI in Kenya; University of Dar es Salaam and Muhimbili University of Health and Applied Sciences in Tanzania; and University of Rwanda

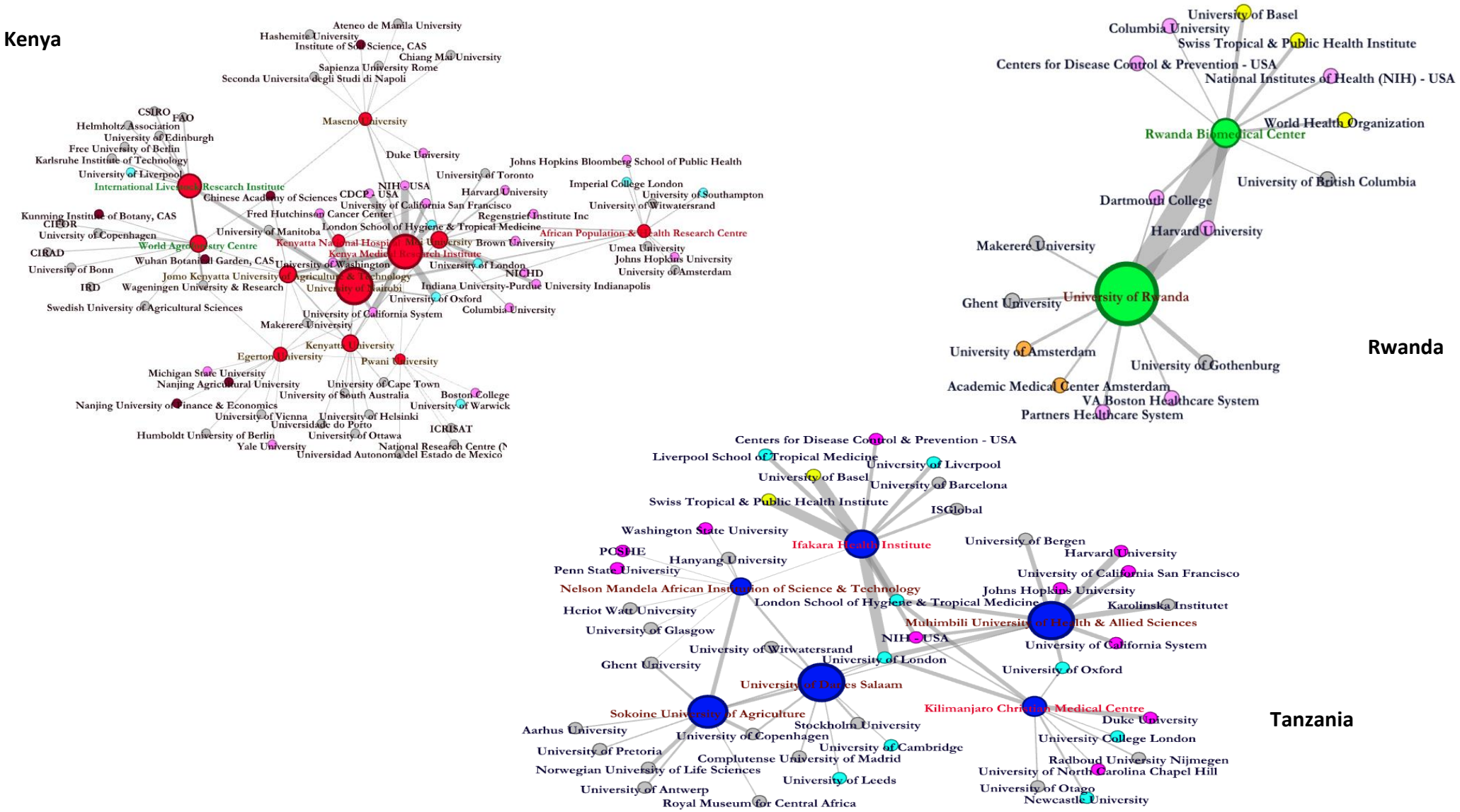


Figure 10: Research organisations networks in Kenya, Rwanda and Tanzania (2011-17)[6]

[6] Source: KSI project elaboration based on WoS data
Notes: Node colors: Kenya (Red), Rwanda (Light green), Tanzania (Blue), USA (Pink), UK (Light Blue), China (Brown); Node size: Number of publications (min=115, max=2116); Edge size: Number of collaborations (top10 for each Kenyan institution);
Labels: Academic (Brown), Research institute (Green), Health institute (Red), Government (Blue).

(e.g. SDGs 1 "No Poverty", 2 "Zero Hunger" and 6 "Clean Water and Sanitation") revealed by an analysis of the SDGs targets indicators[7]. There is a high dependence in the three countries on international research collaboration and international research funding (Public and Philanthropic), that is in health research related areas. Some of biggest funders include the National Institutes of Health (NIH - all institutes combined), Wellcome Trust, Bill and Melinda Gates Foundation and the European Union (EU, ERC, EC, etc.). Overall, findings suggest that the SDGs' research areas which receive most funding, mainly from foreign funders, and in which researchers in the three countries publish most in international journals, are not necessarily the research areas where the countries perform less well with respect to SDGs indicators. In other words, despite the poor performance in SDGs such as 1 "No Poverty", 2 "Zero Hunger", 6 "Clean Water and Sanitation" and 9 "Industry, Innovation and Infrastructure", a small minority of research is related to those SDGs. While these results do not suggest there should be less research on health, it raises concerns that the three countries are not creating capabilities in other priority areas that might be crucial for future development (and which may also be connected to health).

The issue of the nature of alignment and misalignment between research funding and societal priorities has been discussed extensively in academic literature recently. Beyond the allocation of research to different priorities there are also outstanding concerns about the misalignment between research and innovation impact, which were felt by many to necessitate a move from research excellence to innovation systems thinking. The subject is of much current research interest with respect to research, the SDGs and social goals (for example see, Yegros-Yegros, Alfredo et al, 2020; Confraria and Wang, 2020; Novitzky et al, 2020; Kraemer-Mbula et al, 2020; Mutapi, 2019; Wallace and Rafols, 2019).

Although data in this case do not allow to make any causal claim, there seem to be ample space to reflect on how national and international research funding may be revised to address countries priorities (as defined by SDGs), and building of national research capabilities .

4.6 Assessing feasibility of existing metrics in relation to balanced growth and the SDGs

In relation to our ToC (Figure 6) the analysis presented above allows us to assess the feasibility of existing metrics in relation to the SDGs. The use of existing datasets and metrics can provide certain insights e.g. a statistical understanding of the strengths and weaknesses of different measurable components of the KS in different countries, compared to each other. It can also provide an improved understanding of how these components relate to each other.

There are a number of important gaps in the evidence base on the performance of STI investments.

These two insights together can provide a better understanding of where a particular country might prioritise future investments. But it is important to treat such analyses with caution and to realise what this type of analysis cannot inform decision makers upon including:

- Returns on investment may lead to wrong estimations, given the limited role of R&D in the innovation processes in LMICs;
- Returns on Investment from other proxies for KS such as education or technological capabilities would be problematic because these cannot be represented as simple inputs of a production function e.g. number of pupils attending a given school level, and the number of engineers - in the population are not the result of a one-off investment;
- Measurement of strengths and weaknesses in the three countries, and estimation of how they are related dynamically, is subject to a crucial bias: analysis may be omitting components of the KS that are more relevant than those measured, and/or that interact in complex ways with those measured, which may alter the results substantially;
- The project's measure of country priorities is based on the universal concept of the SDG targets and indicators. However, although the SDGs where agreed globally, different countries are likely to have different priorities with respect to targets, and available indicators of the SDG targets may provide a poor representation of what a country may prioritise.

This project makes a series of recommendations (see Section 7) with regard to the above and offers some practical activities that could be taken forward in order to address the limitations highlighted by this study.

[7] For further details please see Annex 3: draft academic paper on mapping the research systems in Kenya, Tanzania and Rwanda.

Section 5: What does the application of the practical concept tell us about knowledge systems in Kenya, Tanzania and Rwanda?

5.1 Setting the scene for the application of a new practical concept

Sections 1 and 2 of this report contend that whilst important and useful, existing dominant research and innovation policy conceptual frameworks can skew analysis, data collection and investment strategies impeding efforts to bridge STI and national development goals in LMICs. A key issue is that important features of local contexts are regularly omitted from analysis and that omission steers and distorts investment in unproductive ways. Another is that standard metrics associated with those dominant paradigms are focused on inputs and outputs. The relationship between those inputs and outputs and development outcomes are often not explored.

A growing body of theory and evidence about STI policy and policy frameworks is emerging, shedding light about changes needed so that LMICs can reap the rewards of investment. These include:

- Diverse perspectives on the ways to reconceptualise research excellence to include broader understandings of that term are emerging in SSA and other LMICs. These perspectives define excellence not exclusively on the basis publications and outputs but rather in terms of outcomes, capabilities and capacity building (Erika Kraemer-Mbula et al, 2020; Chataway et al, 2019).

- The need for a much more nuanced understanding of the private sector. If meaningful connections are to be successfully made between research, industrial, service and not for profit sector communities we need to stop basing STI investment and intervention strategies on the assumption of well-developed formal private sector institutions in contexts where the majority of the private sector is made up of informal sector enterprises (Daniels, 2020; Kraemer-Mbula and Wunsch-Vincent, 2016).

- Acknowledgement of the diversity and value of context specific sources of knowledge and incorporate that knowledge diversity into conceptual underpinnings to STI policy (Fre, 2018; Lebel and McLean, 2020).

In this study, the overall intent is to build on this emerging body of insight and make a first attempt to develop a more systemic approach to understanding and resolving the need for a new STI policy conceptual framework to better align STI to development needs and goals.

Policy documents for the region are very broadly framed towards sustainable development. But there is an unclear line of sight between these broad ambitions and the formulation of national STI policy. This is one explanation of why STI investment are not delivering towards the SDGs.

Figures 3 and 4 above outline ways in which a transformative KS approach can be developed and used to enhance stakeholder engagement, data collection, analysis and more effective approaches to investment. Section 4 outlined ways in which quantitative analysis can be reconceptualised to better inform transformative KS policy, intervention and investment. This current section looks in more detail at ways in which country-based qualitative evidence, data and analysis can shed light on what works to further align STI to national development goals and specifically to the contexts of Kenya, Rwanda and Tanzania.

5.2 Mapping the current STI context in the three countries

This section provides a brief descriptive overview of the current STI landscape in the three countries based on a review of existing STI related policy literature. Topics covered in the section include the major STI policy initiatives that are in play, the intent of these policy priorities and the major STI challenges that these three countries face. This section concludes with some observations about the three different country contexts that are relevant for understanding both the current performance of STI investments, as well as highlighting critical gaps, challenges and opportunities.

Overall, **Kenya** is in a relatively strong position in of terms of investments and capacity in education and R&D compared to other East African countries. Driving the development of the Kenyan STI ecosystem are efforts to create effective policy frameworks through the establishment of three sets of institutions to ensure promotion, coordination and regulation of the STI process, quality, funding and advisory linkage mandates. This is as a result of its open knowledge production system with potential for inclusion of an array of actors and partnerships. Specific partnerships, for instance, the establishment of World Bank (WB) Centres of Excellence (CoE) have continued to promote applied research and training relevant to development priorities in local contexts.

In **Tanzania,** at the outset of this pilot study recent literature described Tanzania's STI ecosystem as still evolving (Davies et al., 2018) and this research certainly observed that the STI ecosystem was less advanced than that seen in Kenya and Rwanda. The country remains heavily dependent on foreign research investment. This has supported STI initiatives in the country, but it has also undermined the utility of knowledge produced as knowledge production activities and may not necessarily align with the needs of the people and national policy priorities. It is not clear whether mechanisms exist to better coordinate foreign research funding and to strengthen its alignment to national priorities and development directions.

In **Rwanda**, the STI ecosystem is currently transitioning to a knowledge and technology driven economy. This transition from Vision 2020 to Vision 2050 is guided by the National Strategy for Transformation (2017-2024) that integrates other continental level ambitions, that both Kenya and Tanzania also aim towards, of the African Union Agenda 2063 and STISA 2024, as well as the SDGs.

Table 2 below summarises the current STI characteristics of the three countries.

In all three countries, there has been a move to establish an enabling institutional architecture. In **Kenya**, efforts to build STI ecosystems include the establishment of enabling institutional arrangements, the National Commission for Science and Technology (NACOSTI) and its affiliate agencies such as the Kenya National Research Fund (NRF) and the National Innovation Agency. In **Tanzania**, COSTECH (Commission for Science and Technology) to provide the national STI regulatory function. However, a functional mechanism to include a wide array of stakeholders in decision making and priority setting has yet to emerge and is an important opportunity that could be built upon to strengthen governance which in turn could strengthen alignment with a wider set of development priorities. **Rwanda** has also set up various systems for coordinating STI activities and enhancing appropriate funding for the activities through the establishment of the National Research and Innovation Fund (NRIF) coordinated by the National Commission for Science and Technology (NCST). Despite this, the country continues to lag behind in research investments while also grappling with appropriate approaches to design current and future investments that could potentially contribute to sustainable development.

We observed considerable variation in the role of state and non-state actors across the countries. In **Kenya**, both state and non-state actors dominate knowledge production and are organised around formal education and research systems and informal systems such as the Technical Vocational Education Training Systems (TVETS). Formal systems such as universities and public research institutions have supported knowledge production in various STI areas particularly agriculture and health. The wider cadre of non-state actors such as think tanks, international and regional research centres have also contributed to this knowledge pool. Whereas in **Rwanda** we observed limited roles of non-state actors in producing knowledge although a few non-state actors are now emerging e.g. Institute for Policy Analysis (IPAR). However, it is evident that these types of non-state organisations would require further support for co-production of knowledge with other state actors. In **Tanzania**, current STI policy efforts are aligned by the development vision of industrialization that is supported by both state and non-state actors producing and using knowledge. State-led knowledge production is mainly anchored on public universities, public research institutions and the Vocational Education Training Authority (VETA).

Rwanda's public system supports the transformative potential of STI with the state playing the biggest role in financing and setting up of knowledge producing institutions, including innovation hubs and universities. Rwanda's knowledge production has centered on collation of all public universities and their constituent colleges into one single university - The University of Rwanda (UoR) (Tvedten et al., 2017), the country's key 'knowledge hub'. Emerging and complementing other public systems are TVETs aimed at equipping the youth with capabilities to help Rwanda achieve its vision around a knowledge-based economy through its manifesto "Made

in Rwanda" policy. The hubs are central in supporting ICT innovations. While the systems and institutional set-up for knowledge production is more clearly defined in Rwanda than other EAC countries such as Kenya and Tanzania, the level of knowledge production is relatively low as the country has not built enough of a critical mass of researchers. Various national agencies continue to support knowledge produced for policy and societal impact. These institutions for example, the National Industrial Research and Development Agency (NIRDA) have been key in setting the agenda and enhancing clear flows between knowledge production and use both in the formal and the informal sector. They do so by responding to challenges of technology and adoption through the establishment of incubation centres, entrepreneurship training, promoting public-private partnerships, capacity building in small and medium enterprises, and providing prototype development services. For example, kLab and Fab-lab innovation and incubation hubs have succeeded in ideation and co-creation of knowledge while addressing societal problems. However, there is still a need to design them as more interactive problem-solving investments and thus a much more analytical understanding on how they can evolve to support more societal impact is required.

In **Kenya**, knowledge production efforts are widely supported by the NRF through institutional research grants, university research and postgraduate studies. Other partnership types with international development partners have targeted building a critical mass of researchers e.g. the Newton Utafiti Fund established in 2017 in partnership with the British Government supporting collaborative research and knowledge transfer through capacity building.

The African Development Bank (ADB) and the World Bank (WB) also continue to finance knowledge related activities through collaborative support of university graduates and ICT innovations respectively. Other government funds include the youth enterprise development fund, Uwezo fund, and, women enterprise funds. However, some of these funds e.g. Uwezo fund have suffered reputational damage through scandals and corrupt officials running the funding process. These funding schemes remain uncoordinated and therefore hard to link to impacts. Despite many initiatives, brain drain continues to be a great challenge even as governments put measures to mitigate the loss of talent. According to Kenya's National Science Commission and other stakeholders, strengthening dialogue between Universities and Industries is considered a promising niche to strengthen knowledge impact. Experience in the country so far shows that these sort of dialogue can be enabled through partnerships as well as knowledge brokerage. This is supported through one of the case studies undertaken which looked into the ***mechanisms for linking knowledge production in the Universities i.e. Strathmore University (SU) and Jomo Kenyatta University of Agriculture and Technology (JKUAT)***. However, this case study also suggests that promotion of and coordination of knowledge production and use require specific intermediary roles and capabilities such knowledge brokering to link university to industry and that these capabilities need further development and support over an extended period of time.

In Tanzania, a relatively vibrant set of national think tanks and consultancy firms exist, and these continue to spur international partnerships for enhanced knowledge production in various fields including in areas related to the SDGs. Despite this vibrancy, Tanzania continues to experience deeper challenges in the quality of education and an unmet (or weak) demand of STI graduates; low research capabilities; lack of linkages with the end users and, limited use of research results. While there is potential for vibrant non-state systems to support Tanzania's knowledge base, spaces/platforms for integrating such potential into Tanzania's mainstream vision remains relatively underdeveloped.

With regard to our analysis seeking the explicit alignment of STI policies to the SDGs in the three countries, discussions with relevant platforms in Kenya, such as Linking Industry With Academia (LIWA) and the national/international think tanks affirms that impact networks are a great opportunity but requires sustained funding for sustainability. This is reflected in the ***case study of Kenya's Utafiti Sera[8]:*** **a platform for research evidence into policy use and uptake** and represents one of a number of recent initiatives in Kenya to build research-impact network in the social science discipline. Promotion and coordination of research into use initiatives requires champions to promote research evidence into policy use as revealed by the case study. There is potential to replicate such models across other SDG areas, but this will need stronger coordination and the development of more consultative platforms for learning and knowledge use. In Rwanda, the Government has established its Science Granting Council that has now set budgets for funding facilities such as industrial incubation centres and product laboratories, implying more targeted funding for specific industrial outputs

[8] *Utafiti Sera* is Kiswahili for research-policy

Table 2 Mapping of current STI trajectories and key characteristics of the knowledge systems in Kenya, Tanzania and Rwanda

	Kenya	***Tanzania***	***Rwanda***
Policy framing and governance	Framed by Kenya's Vision 2030 and Big 4 Agendas. Policy environment is focused on creating agencies (NACOSTI and NRF) that could support production, coordination and regulation of knowledge with emphasis around production of knowledge and research skills for development. STI arena is characterised by myriad of state and non-state actors producing and using knowledge. Strong on knowledge production but less on integrating production and use.	Current STI policy has developmental vision of industry Guided by the Vision 2025, established policy institutions, COSTECH as key regulator and NFAS as the funding body. Institutional set-up still in infancy with knowledge systems largely supported by foreign institutions. Foreign investment supports STI initiatives but to the detriment local knowledge production aimed at societal need.	Transitioning from a knowledge based and technology-led economy (Vision 2020) to a transformative STI underpinned by social transformation, economic transformation and transformational governance (Vision 2050). The National Council of Science and Technology is the regulatory agency for STI. Various systems for STI coordination and funding enhancements e.g. NRIF and NCST.
Role of state and non-state actors in STI policy implementation	More open knowledge systems where both state and non-state actors dominate and support STI policy implementation.	Steers national vision of industrialisation through teaching, research and community engagement. Potential for vibrant non-state systems to support knowledge base, spaces/platforms for integrating such potential into mainstream vision remains relatively constrained or unclear.	State led systems supporting the transition to a transformative STI with focus on ICT innovations. Very limited role of non-state actors producing knowledge not aided by limitations in both research capacity and funding. Emergence of private universities and think tanks.
Balance between knowledge production and use in STI policy	Robust knowledge production compared to other East African countries but unclear pathways linking knowledge produced to use in order to achieve impacts.	Emphasis around knowledge production through universities, innovation hubs, VETA, Challenges in linking knowledge produced with end users.	Public systems developed to support knowledge production through the "University of Rwanda" a key knowledge hub and establishment of innovation hubs, TVETs.
Explicit alignment of STI policy to SDG agenda	Initiatives such as *utafiti sera* supporting efforts to get policy into action e.g. in areas of urban governance focusing on human rights for the poor affected by infrastructure and social protection. Various university industry partnerships are emerging and are focusing on partnerships that promoting Indigenous, ethno-botanical knowledge while other partnerships are blending business and community interests.	A few examples of initiatives of state and non-state led are emerging to support this e.g. investments in VETA , novel initiatives through the universities where universities like Sokoine University of Agriculture is supporting knowledge production and use through village knowledge centres.	State led initiatives supporting and recognising traditional health practices as part of the overall health system are enabling the poor to access health services as they lack access to formal medical services. Increasing ambition to leverage the transformative potential of STI.
Key capacity building priorities identified in STI policy	Support measures for tracking returns on investments in different sectors including data/platforms within STI agencies. Integrating the role of non-state actors e.g. the private sector into Kenya's institutional framework.	Research capabilities, governance strengthening through inclusion of a range of actors.	Support building critical mass of researchers for knowledge production, investment in and strengthen of existing non-state led actors in knowledge production e.g. private universities and think tanks.
Key priorities acknowledged as requiring attention	Need for clear pathways in policy documents for ensuring knowledge use beyond production. Integration of the private sector players to operationalizing the ST&I policies, supporting research into use. Facilitating formal and informal knowledge systems interactions.	Weak research into use, weak governance, structural bottlenecks, lack of linkages between production and use of knowledge, incoherent institutional policies.	Inclusion of an array of informal governance actors in STI planning and implementation could help balance state-led tendencies and the reliance on private industry delivery pathways. Limited role of non-state actors producing knowledge is held back by limited research capacity and limited funding.
Mapping research investments	High dependency (47%) of the research system on external research funding mostly focused on health research.	High dependency of the research system on external research funding mostly focused on health research. External funding accounts for 42% of STI activities but	High dependency of the research system on external research funding mostly focused on health research.

		this also reinforces the misalignment to actual societal need.	

and outcomes. The governance framework has also created systems for enhancing appropriate funding for R&D activities, through the establishment of the NRIF coordinated by the NCST. Apart from the Government annual allocation of 0.5% of the total budget to the NRIF, there is recognition that more funding in STI activities are to be sourced through collaborative efforts in both bilateral and multilateral research projects.

5.2.1 Findings and Implications of the STI context in the three countries.

The description above of the STI context in the three countries draws from a range of existing STI policy reviews and analysis. While this is useful in a painting broad picture of the STI context much of this analysis conforms broadly to a national innovation system framing. This is useful because it highlights the importance of bridging gaps between knowledge production by research and knowledge use by the private sector and others. However, it also means that less attention is given to the purpose to which innovation is directed (other than economic growth) or the values that underpin decisions and goals. While policy documents for the region are very broadly framed towards sustainable development there is an unclear line of sight between these broad ambitions and the formulation of national STI policy. This is one explanation of why STI investment are not delivering towards the SDGs. Moreover, there is a lack of clarity about the purpose to which STI investments are being deployed which also suggests that existing STI policy frameworks in the three countries, and the processes through which priorities and future directions are set, needs to be updated to better account for the explicit and widening impact agenda implied by the SDGs. It is precisely these challenges that the KS concept developed by this project sought to address.

5.3 A closer look at STI investment in context: evidence and explanations of what is working, challenges and over-looked opportunities.

Using our KSI conceptual framework, this section organises its analysis around three lines of enquiry needed to understand STI investment performance and design:

- the existence of a diversity of different approaches and pathways aligned to the SDGs;
- the inclusion of informal sector knowledge activity and the integration and leveraging of SDG impacts it has to offer;
- the directionality of impacts, specifically the explicit targeting of inclusion and sustainability impact as part of economic growth efforts.

This section has three objectives:

(i) exploring the diversity approaches aligned to the SDGs;
(ii) providing evidence and explanations of what is working well, what is not working and why and needs further attention;
(iii) identifying opportunities for amplifying SDG relevant STI approaches and overlooked opportunities particularly in relation to the informal sector.

Our in-country reviews tell us that existing bodies of evidence on the impact of STI interventions in the region are thin. There are many analyses of the challenges of the STI environment and a range of policy prescriptions for this, but little clarity on how this could be converted in an operational strategy.

What was the evidence?

The analysis that follows is based on a review of secondary sources, supplemented by six more in depth case studies. The case studies also drew upon published secondary sources as well as key informant interviews. In commencing this work it was anticipated that it would be informed by a body of published material, including programme evaluations and published research that would provide impact evidence to make judgments about the what was working or not and why. However, an extensive search process revealed that across all three countries there is very little evidence available. To be clear, there is published material on a wide range of different forms of STI intervention (and this forms the basis of the discussion below). Yet what is missing are detailed analysis and evaluation of the impact and performance of these interventions. There are often figures available on outputs of STI programmes and strategies, such as numbers of students sponsored through degrees, literacy rates, mobile phone penetration

and internet access, participation rates in Farmer Field Schools. But, the outcomes in terms of improvement in social, economic and environmental indicators are not known.

This is a key finding in itself as it is apparent that there are **major gaps in the evidence base on STI investment performance**. Without systematic and long-term monitoring of the outcomes of specific interventions it is impossible to assess the impacts of contemporary patterns of investment in relation to the SDGs. This observation is discussed further in the recommendations in Section 7.

5.3.1 Exploring the diversity approaches with promising SDG intent

Despite the lack of impact evidence, it is possible to identify a diverse set of STI interventions and knowledge related activities with SDG intent or value and to develop a picture how these interventions are playing out. The following illustrates the diversity of intervention encountered in the three countries.

There are a significant number of novel initiatives and activities which drive social innovation, but also product and service innovation. These might contain disruptive models of innovation. Importantly they can include the potential to strengthen key knowledge system interactions and nurture a wider STI landscape that is conducive to SDG aligned outcomes.

In **Kenya** the expansion of TVET institutions, managed by decentralised county level governments, has been very significant in widening access to practical skills training (Gicharu, 2018) and bridging formal and informal sectors (Kipkirui, 2018). Pasha Centres (Digital Villages), a programme launched in 2010 supported through public private partnerships are an attempt to support informal knowledge production and use from the bottom-up by setting up 'cyber cafes' in rural villages to provide public access to a range of e-services and act as local hubs for knowledge exchange. There are also efforts to promote farmer-led innovation through a number of initiatives e.g. the Prolinnova network, A Growing Culture (AGC) and the Farmer-Led Innovators Association of Kenya (FALIA). The importance of indigenous knowledge is also beginning to be recognized and the Kenya Resource Centre for Indigenous Knowledge (KENRIK) and the Centre for Biological Diversity (CBD) are engaged in documenting, preserving and disseminating indigenous knowledge held by different communities across Kenya. A number of private and public business incubators are focused on supporting green businesses including the NETFUND program and the Kenya Climate Innovation Centre. These and business incubators such as Nailab, IMB research in Nairobi and @iLabAfrica at Strathmore University have shown signs of success in building strong links with industry and with local communities and generating new businesses.

In **Tanzania,** the Tanzania Industrial Research and Development Organization (TIRDO), a parastatal research organisation, has provided consultancy services to industry to support multinational companies to use indigenous and informal knowledge and technologies in the development of products and services for poorer communities. One outcome has been a collaboration between Coca-Cola Kwanza Ltd and local household stove manufacturers. The Small Industries Development Organisation (SIDO) has acted as a knowledge broker, setting up incubation centres and networking SMEs in Tanzania with SMEs in India and South Africa. The Economic and Social Research Foundation (ESRF), United Nations and the Government of Tanzania set up the Tanzanian Knowledge Network (TAKNET) in 2009 to provide a forum for exchanging and sharing information on social and economic development. Such forums have grown to include initiatives like the "innovation week", an annual networking event to connect people and ideas. These forums have attracted huge interactions on ideas and innovations although the impact of such interactions among various knowledge ecosystem players is yet to be evaluated. The College of Engineering and Technology's "Clubs, Clusters and Incubators Programme" at UDSM reaches out to farmers groups, women, youth and recent graduates in rural communities to support the development of agri-businesses and other start-ups.

In **Rwanda**, a number of national-level policies specifically targeted at linking formal and informal activities and knowledges are supported. This is in contrast to Kenya. The recently launched 'Made in Rwanda Policy' established the 'Home-grown Department' to promote informal KS through programmes to support local-level problem solving for poverty related problems and encouraging collaboration between informal sector and the formal private sector and TVETs. The Directorate of Science, Technology and Research (DSTR) under the Ministry of Education (MINEDUC) also directs local and international funding into research encompassing formal and informal sectors such as traditional healers and medicine. For example, NIRDA has supported investments in

setting up of a research facility to codify the efficacy of Rwanda's medicinal plants used in traditional medicine has organised a series of dialogue processes used to engage traditional healers. While this presents an opportunity to bridge indigenous knowledge sources into wider KS and mainstream development activity, it is still unclear what outcomes these efforts have had. The third sector has also played a role in supporting informal sector innovations and one example of an apparently successful project is the work of Oxfam on pineapple farming and processing (FEI, 2016).

Implications

There are a number of important points that emerge from the above as an illustration of STI intervention diversity. It appears that what can and indeed what needs to be considered part of each of the countries' STI investment portfolio is probably much wider than that is reflected in standard STI policy reviews. Clearly, many initiatives are underway that have relevance to the SDG agenda that could not only be built up, but could also be a source of lessons for a future facing STI agenda. We have already lamented about the lack of evaluation studies to draw upon but moreover there is a weak tradition of evaluating STI investments generally, but this becomes of heighted importance when novel approaches are being tested to specifically target new goals like the SDGs.

The evidence presented above also reveals that many of these initiatives have emerged "in context". For example, in Rwanda, where research capability is still developing, the emphasis has been put "home grown" "Made in Rwanda" as a way of tapping into a wide range of formal and informal knowledge sources. In contrast, in Kenya with its strong ICT, research and private sector history, interventions are being made to build on these strengths and resources. Tanzania has an entirely different political and STI history and pursuing options to of state led industrialisation around SME development. So while the patterns of diversity that have been observed suggest the green shoots of a different sort of knowledge system emerging, novel approaches cannot simply be transferred across countries and regions, but need to be understood and supported *in-situ*. Our KS concept also places value on creating the conditions for both amplifying these promising initiatives as well as encouraging STI policy to enable the emergence of an expanding range of these types of experiments in leveraging SDG impacts.

Despite stressing the importance of context in the emergence of these initiatives, there are also some distinct patterns of initiatives that are apparent.

- **Linking research to the private sector.** Initiatives that seek to develop partnership between universities and other public research organisation in order to "commercialise" research finding and or establish new business offering.

- **Bridging informal and formal sectors**. These take many forms including: searching for solutions in informal sector innovation, particular because of the informal sector's ability to tap into the needs of poor communities; or extending training and regulation to the informal sector to upgrade skills and practice.

- **Enterprise development.** These can take the form of business incubation hubs to help develop ideas into business opportunities. In countries where the private sector has limited capacity this might for example involve developing SME through capability or technology upgrading.

- **Knowledge sharing platforms and networks**. There is considerable diversity of these initiatives that range from long established civil society networks to purposeful interventions targeting missing knowledge brokering mechanisms in particular domains of knowledge production and use.

The next section draws on the six case studies undertaken as part of this pilot study to explore what is working and what needs attention in these types of intervention.

5.3.2 Explanations of what is working well and what needs further attention

Guided by the national advisory committees established by the project, six case studies were selected to explore in more detail STI interventions that could shed further light on novel and emerging areas of STI activity. The

summary analysis of these case studies in Table 3 (a-d) focuses on what is working well, and what needs more attention.

5.3.2.1 Linking research to the private sector

A recurrent theme in stakeholder engagements and the review of STI policy analysis in the three countries is the challenge of translating research into innovation and impact and particularly the use of research by the private sector. A case study was conducted to explore contrasting experiences of research-private sector linkages in a public university and a private university in Kenya. The case study highlighted that the success of universities working with the private sector is largely determined by the alignment of the organisational culture of the university to the private sector and the existence of established relationships and networks. Not surprisingly the private university had most of these necessary starting conditions and was forging ahead, establishing successful specialised centres to build collaboration with the private sector. The public university with culture of public good activities and community engagement has a much less well developed tradition of working with the private sector. It did, however, prove effective in developing partnerships with local government and other development agencies and this was helping translate research and related expertise into SDG facing activities. The case study raised questions about whether the private sector (and the market more generally) is going to use research for products and services aligned to inclusion and sustainability. Some of the private universities specialised industry engagement centres did explicitly focus on sustainability and inclusion related issues. That said, it was apparent that linking to the private sector does not guarantee these sorts of outcomes even where a vibrant enterprise sector exists in countries like Kenya. More explicit incentives would help this targeting. The public sector university had a set of rather ad hoc research into use arrangements targeting community needs. Building the capacity of the university to refine these arrangements into a robust model could help accelerate the impacts of an organisation that is already well directed towards the inclusion sustainability agenda. In the wider review of STI analysis for the three countries it was evident that the private sector is often small-scale, often informal sector and with limited capacities for knowledge absorption innovation. Reliance on partnerships with the private sector to deliver impact from research therefore needs to be tempered with a reality check on the capabilities and motivations of the private sector in the region.

Table 3a Linking research to the private sector

Case study	What works well	Challenges encountered	What needs attention
University-Industry linkages in different organisational settings in Kenya	Privately owned university with private sector governance, actively focused on business service, driven by alumni networks in the business community makes partnership with the private sector easier. Public university have a stronger community/ public good orientation and networks. Allows for a variety of innovation pathways with SME private sector led commercialisation but also with community and other development partners. Private university establishing specialised Centres focused on	Inclusion and sustainability issues not necessarily the core intent of partnership with the private sector. Public university yet to arrive at a model research – user interface needed to deploy the range of research products and expertise that it holds.	Private university could be provided with greater incentives from the public purse to find a better balance between the economic, social and sustainability benefits its leverages from its private sector collaboration. In a public university, capacity building, institutional development and creating space for new models and patterns of partnership could help accelerate an organisation that is already well directed towards the inclusion sustainability agenda.

	issues related sustainability e.g. Kenya Climate innovation Centre with strong focus on supporting SME's launching climate smart innovation.		

5.3.2.2 Bridging the informal and formal sectors

The importance of the informal sector in the economies of the three countries is attracting growing recognition. This includes both informal entrepreneurial activity, skills and knowledge as well as bodies of traditional knowledge and practice, health care, ecological management etc. Two case studies explored interventions in this domain. One looked at training and skill development hubs that sought to upgrade the capacity of young people working in and around the informal sector in Tanzania. The other investigated Rwanda's experience with linking traditional healers into formal medical systems. The Tanzanian case demonstrated that targeting vocational skills can be an important avenue for upgrading business practice in the informal sector and that with the right incentives and targeting, can lead to businesses that address inclusion and sustainability issues. However, it also highlighted the way this can further silo the informal sector if functional links are not developed with academic and formal sector business as part of this process. The Rwandan case tracked the informal sector by first organising and registering traditional healers as a pathway to integrating them in the health system. The private sector was brought in as a partner to help develop commercial remedies based on traditional knowledge. As we observed, both of these strategies have benefits and drawbacks. Regulation runs the risk of marginalising traditional healers in the development of standards and norms for traditional practice. When partnering with the private sector it is not clear how benefits are shared with the traditional healer community or how the intellectual property rights are managed for the greater good of Rwanda more generally. Enrolling traditional healers in the health care system offers the potential to expand access to poor communities. However, a critical precondition is building the capacity and awareness of the formal medical system to recognise where traditional practice can complement formal medical treatments and practices. In the wider review of STI analysis for the three countries there are numerous examples of potential valuable informal sector activity and support initiatives aligned to the SDG's. Yet, these seem to be viewed as "niches" for protection or domains to be formalized. The challenge is to find ways to support and integrate the informal sector in ways that better deploy the innovation pathways it holds and help it influence parts of the STI landscape where lessons on targeting poor communities are really needed.

Table 3b Bridging informal and formal sectors

Case study	What works well	Challenges encountered	What needs attention
Buni Innovation Hubs versus Tanzania Vocational Education Training Authority (VETA) Programmes	Specifically targeting youth from poor and marginalised communities to upgrade business skills to apply in the informal sector. Use of experience rather than academic entry requirements. Special externally funded projects have helped target start-up focused on sustainability relevant business models, for example recycling plastic material.	Weak collaboration with the formal business sector and academic and research institutes (remains in the informal sector silo). Legal framework where imported products are prioritized more that local innovations developed. Historical views and opinions around informality makes majority of people shy away from these initiatives. Also reflected	Reduce bureaucracy to encourage private sector linkages and more collaboration formally and informally with the local academic institutions. Stronger targeting start-ups with inclusive and sustainability business models. Establishment of Centres of Excellence to enhance capacities targeting emerging industries/ technologies, e.g. mining ICT.

		public funding allocation.	
Medicinal plants research and engaging traditional healers In Rwanda	Regulation helps recognise traditional health practices as part of the overall health system. Organising traditional healers to into groups/societies helps regulation. Partnering with the private sector in product development brings much needed financial support and pharmacological expertise in product development and marketing. Building the capacity and awareness of the formal medical system to recognise where traditional practice can complement formal medical treatments and practices	Regulation runs the risk of marginalising traditional healers in the development of standards and norms for traditional practice. Partnering with the private sector: not clear how benefits are shared with the traditional healer community or how the intellectual property rights are managed for the greater good of Rwanda more generally.	Build the capacity of traditional healers to regulate their own practice and bringing in formal science perspectives to compliment the basis upon which remedies and practices are assessed. Traditional remedies need specific regulation to ensure ethical and inclusive business practices are pursued. Succession and preservation plans for the sector are also not clear. The actors in this field are ageing and traditional knowledge needs to be documented and preserved.

5.3.2.3 Enterprise development

Business incubation hubs and start-up accelerators are an increasingly common feature of innovation-ecosystem centric forms of development assistance and national STI policy. Unsurprisingly, our review found many examples, and this reflect the need in many countries to build innovation capacity. Two such examples were explored as a case study in Rwanda. Both examples showed impressive numbers of young entrepreneurs passing through their programme of support. While the number of successful business to emerge was ambiguous, it was apparent that an approach of entrepreneur trainees co-developing products and services communities have led to communities embracing/trusting and using the innovations. A focus on ICT aligned with strong government regulation and support for ICT, ensured that the enabling environment for entrepreneurial activity was in place. Blended public and private sector financial support was also found to be helpful. Despite these promising conditions, challenges were also encountered. The structure of the hubs tended to promote an ideas into commercialization pipeline, irrespective of the stated desire to co-innovate with communities. Formal links with academic and research institutes was either weak or absent. Providing young entrepreneurs access to financial resources was a key bottleneck. Success metrics focused on “bums on seats” rather than outcomes achieved. Lack of follow-up support in the commercialisation process reinforces the impression of an input driven training programme. Furthermore, despite the Rwandan public and private sector funding, it was unclear how hubs can be sustained in the absence of external project funding. On reflection, these challenges suggest that the hubs studied were a step in the right direction, but that the capacity and resources to run them effectively has yet to emerge. A lack of clarity about how the success of these initiatives is to be judged also suggests that it is going to be difficult to continuously learn and improve the performance of these in a general sense, but more importantly target performance improvement towards inclusion and sustainability. Across the three countries an empirical question remains about the extent that enterprise development and purely market driven efforts can deliver SDG relevant innovation and outcomes. There is still a lot that needs to be learnt about how to design and manage incubation hubs for that purpose.

Table 3c Enterprise development

Case study	What works well	Challenges encountered	What needs attention
kLab and Fablab incubation centre in Rwanda	Mixed government private sector funding. Products and services co-developed with communities have led to communities embracing/trusting and using the innovations.	Path dependency approach of ideation, prototyping and letting go to the community. Narrow way of integrating knowledge production and use as it is an iterative process. No formal links with research or academic institutes Providing young entrepreneurs access financial resources a key bottleneck. Success measure by numbers enrolled. Limited evaluation of impact or sustainability of new enterprises Unclear how hubs can sustain in the absence of external project funding.	After care support to further enable the entrepreneurs to reach commercialisation. Continuous research and development support by the hubs especially with the strong alumni network. Setting up of innovation hubs along with academia so that angel investors along with academia can be

5.3.2.4 Knowledge sharing platforms and networks.

The importance of mechanism to broker knowledge between producers and users of knowledge is seen as critical in an effective KS. This function sits between research and industry, policy and other users, between formal and informal knowledge sectors and between members of communities of innovators and practitioners who seek to achieve new outcomes. Two contrasting case studies were explored in Kenya and Tanzania. The first looked at a social science research into policy use platform in Kenya and the second exploring a village knowledge centre (VKC) established by an agricultural university in Tanzania. In both cases, the core framing and focus of the initiatives placed issues of inclusion and sustainability centre stage. The platform in Kenya targeted urban governance and that of VKC in Tanzania explicitly operated as a mechanism for identifying, negotiating and brokering shared value opportunities that benefited small-holders and the private sector. The success of the Kenyan initiative was, to a large part, enabled by the way that Kenya decentralised its governance (down to county level) which has opened up space for local participation in policy making processes. In the Tanzanian case, although the initial success focused on dairy value chain development, it was able to evolve and mature into a knowledge exchange for a diverse set of topics beyond agriculture. Both faced political economy challenges. In Kenya, powerful interest groups tended to dominate discussions. In Tanzania, the influence of external project funders dictated the focus and approach of the intervention (e.g. the focus on a particular technology solution to animal nutrients when other appropriate and local options were available). A final similarity was that both of these very promising interventions were almost entirely reliant on external (international) time bound project funding, raising questions about the long-term sustainability of the approaches pioneered. There were also opportunities for strengthening these initiative that resonate with other examples observed in the region. In the case of the Kenyan platform, broadening the participation of stakeholders beyond the research and policy community could have created different visions and interpretation

of research evidence aligned local development agendas. In the Tanzania case, capacity building in the university could help it learn from its experience and develop the capability to establish centres of excellence in the translation of research into shared value innovation process, that would in turn influence the research and teaching agenda of the university. The bigger message derived here, is that such promising STI initiatives need to be embedded in a broader programme of organisational development if they are to be sustained beyond pilot projects.

Table 3d Knowledge sharing platforms and networks

Case study	What works well	Challenges encountered	What needs attention
Utafiti Sera: a platform for research evidence into policy use and uptake in Kenya	Selection of urban governance as a focus area had high relevance to poor communities and environmental issues. Creates safe space where research findings can be discussed, house rules emphasis simple language, open debate and respect for different points of view. Uses policy champions responsible to ensure evidence is taken up for policy use. Decentralised governance (down to county level) has opened up space for local participation in policy making processes.	Powerful interest groups can dominate discussions. Political and administrative challenges. Limited engagement of targeted communities There is a tendency to seek compromise to keep stakeholders at the table, otherwise key stakeholders walk away from the process defeating the object of being inclusive.	Better mapping of actors involved in social protection and other areas to encompass both formal and Informal actors including traditional authorities, state bodies, NGOs, Faith based groups. External funding scheme seem not be working, "One off" does not work. There's need for funding mechanisms that considers the policy cycle process and not evaluating the program based on the output. Mismatch of funding cycle (2 years) and policy process cycle (can be 5 years or more).
Sokoine University of Agriculture's Village Knowledge Centre in Tanzania	Explicitly operated as a mechanism for identifying, negotiating and brokering shared value opportunities that benefited small-holder and the private sector (e.g. dairy). Evolved and matured into a knowledge exchange for a diversity of topics beyond agriculture.	The influence of external project funders in determining the focus and approach of the intervention. Market based approach are not a panacea and issues remain about distribution of benefits, particular to households that can't take advantage of market-based innovation. Unclear how approach can be sustained in the absence of external project funding. Also, capacity challenges in the university.	The University could be developed into a centre of excellence that helps build capacity and learning on more effective ways of mobilising agricultural research for social and environmental benefit, experimenting and evaluation different approaches in brokering shared value innovation.

5.3.3 What can we say about why STI investments are not delivering to the SDG agenda

While clearly it is not universally true that STI investments are not contributing to the SDGs, there are causes for concern and indeed this was a founding rationale for this pilot project. The evidence and analysis generated by this project suggests that there is not one single explanation of STI's non (under) delivery. Rather there are a clutch of systemic problems that play at different scales in the three countries in remarkably similar ways.

The first concerns the explicit and implicit use of national systems innovation (NSI) as the dominate framing of the policy narrative in the three countries. This project's review of a range of STI analysis and planning documents noted that most of this has been conducted through the NSI framing. Stakeholder dialogues were also found to reflect this perspective. There is clearly value in this framing as it explicitly places innovation (and thus impact) centre stage in economic policy and recognised innovation as a process distributed throughout the economy and that it encompasses much more than R&D effort. However, the tendency of NSI (and its close relative, innovation ecosystems) is to give primacy to the private sector and the market as the key driver of the direction of innovation without questioning the core values and directions of innovation that will be pursued suggests a lack of clarity about the purpose to which STI investments are being deployed. This is not to say that STI policy makers in the region are not interested in inclusion and suitability outcomes as well as economic growth. Rather that the dominant framework does not provide them with leverage points and investment options that could make this wider agenda explicit in STI policy. This is reflected in our finding from the reviewing policy documents for the region: these are very broadly framed towards sustainable development, but there is an unclear line of sight between these broad ambitions and the formulation of national STI policy. Opening the dominant policy narrative to different STI theories of change that are more explicit about the types of outcome that are desired would be timely. This could be achieved by bringing in different voices into policy debates. But it could also be achieved by deeper reflection and analysis of the performance of existing STI investments against performance criteria of the emerging development agenda of the SDGs. At a time when the performance criteria are expanding beyond economic growth, it should not be surprising that STI investments of the past are no longer delivering now that the goal posts have been moved.

The second point follows from this and concerns the lack of evaluation of STI performance. As the economics component of this project has highlighted, at the macro level, judging the impacts of STI investments is extremely difficult due to the complexity of factors that mediate the translation knowledge into different types of outcome. There are methodological challenges to this, but also data gaps due to the historically defined patterns of routine data collection that tend to be restricted to technology and innovation inputs and outputs. These challenges hamper the ability of STI investments to deliver at a macro level because of the inherent difficulty in being able to understand (and prioritise) investments that are delivering well. Moreover, this challenge is compounded by a poorly developed tradition of monitoring and evaluating STI in the three countries. This is the case at both the level of STI policy and at the level of individual interventions. This project struggled to find a body of published material, including programme evaluations and published research that would provide impact evidence to make judgments about the what was working or not and, why. Without this type of evidence base it is difficult to select and design different investment options, or to trouble shoot and upgrade promising approaches that could be built upon. National scale metrics and evaluation certainly need to be part of the solution to defining broad directions and priorities. A level of granularity is also required for the improved design and targeting a specific interventions. Thematic evaluations of e.g. innovation hubs or public-private sector partnerships could be one way of generating more planning and design insights. Case studies of novel or niche interventions is another. As our case studies have demonstrated, even a fairly rapid case study approach can highlight some quite fundamental and generic challenges and opportunities that, at least, warrant further investigation. A final critical consideration in strengthening evaluation is the need to include a wide set of stakeholders in framing performance and evaluation criteria.

The third point concerns distortion and perverse outcomes of STI investments. The bibliometrics analysis undertaken by the economics component of this project very clearly illustrates the dominance of international collaboration in research which has skewed research effort away from SDG relevant topics and more generally away from local development agendas. These same distortions of objectives are also apparent in our case studies where interventions are project funded. This is not to undervalue the important capacity building role of international collaboration. Rather it is the power of external funding sources to determine the way scarce resources are directed. A second distortion concerns the pivotal role the private sector is given in STI

investment. In one sense this distortion is because of the limited ability of the underdeveloped, often informal, private sector to play the role in impact delivery that is imagined for it. More fundamental are concerns about the core values that the private sector and the market may wish to follow. There is no doubt that entrepreneurship is the engine of economic growth. But can entrepreneurship and market forces alone drive innovation for inclusive and sustainable development? This is a particularly pertinent question in the three countries studied where consumer preferences have yet to translate inclusion and sustainability ambitions into market value. This is a distortion that could be managed by policy incentives and regulation, but that needs to be hard-wired into STI investments and the capacity in the region. The final distortion concerns political economy influences of STI priorities (Chataway et. al. 2017). This research observes that STI governance has relatively restricted participation beyond the science and policy community and this that this is likely to circumscribe the way priorities are defined in relation to broad societal needs. The political economy around the understanding of research excellence and the perverse incentives this creates, valuing science excellence over impact excellence is another example.

The final point concerns a range of capacity issues. The work under this project on the review of policy analysis in the region points to many familiar NSI failings. Weak links between research and research users, underdeveloped research capacity, lack of knowledge brokering functions etc. etc. The economic component of this project suggested that economic performance of STI investment was conditioned by the presence or absence of critical KS domains (such as education or ICT capability). The case studies undertaken by the project present a much more nuanced picture of the capacity issues, often either presenting as second order challenges or issues that prevent promising initiatives enduring beyond pilot phases. For example, bringing in the private sector in Rwanda to help commercialise traditional remedies requires regulations to safeguard intellectual property and profit sharing. Enrolling traditional healers in the health care system needs capacity building of formal medical practitioners to understand where the complementarities exist. The incubation hubs in Rwanda suggest that the weakest link is the ability to provide long-term technical and financial support to emerging enterprises. Promising approaches in public universities in both Kenya and Tanzania suggest that promising STI initiatives need to be embedded in a broader programme of organisational development if they are to be sustained beyond pilot projects. And most notable of all, it that most promising STI initiatives rely on project funding. Taken together this is a perfect storm of missing elements that are needed to ensure that often well-conceived STI interventions are able to deliver the impact they promise. It is clearly not practical to suggest that capacity development need to be tackled as a systemic issue across the whole of the economy in the three countries – although this might be the only way to deal with the thorny issue of project based funding challenges. However, it does suggest that more attention needs to be on organisational, institutional (rules, professional incentives), policy and regulatory development in specific STI intervention design.

5.3.4 Identifying opportunities for amplifying SDG relevant and overlooked STI approaches

One of the key findings of this pilot study was the plentiful supply of promising activities in both the informal sector and in domains outside the usual STI policy sphere of interest in each of the three countries.

Evidence reveals that informal knowledge sector e.g. the '*Juakali*' sector (informal engineering and manufacturing) in **Kenya** builds on peoples' capabilities (e.g. entrepreneurship skills, needs and aspirations), making them able to serve and empower people better. This informal sector, however, would benefit from better links to the formal sector resource, knowledge and opportunities, and by being monitored and recognized as an important part of the knowledge ecosystem. It would be a mistake to try and formalise the informal – what would be desirable is to have them better integrated so as to leverage their disruptive effects on the STI environment at large.

In each country there is significant informal sector knowledge activity of high relevance to local communities and the SDGs but they tend not to currently be part of the mainstream STI conversation, and thus opportunities to be an integral part of wider transformative change are overlooked in STI planning and investment.

Although TVETS are some of the efforts being established country-wide, as a means of strengthening the informal sector, they are still characterized by low levels of education which do not match the formal requirements. To this end, many innovation and useful informal knowledge activities remain untapped for social and economic gains. Additionally, initiatives such as *utafiti sera,* which support efforts to get policy into action have demonstrated potential to address SDG. The platform has focused

on a number of areas including urban governance which deals with issues to do with human displacement by roads, human rights and especially the poor affected by infrastructure and social protection in Kenya. The initiative has managed to influence cash transfer mechanisms to the poor through taking such payments closer to the recipients. Generally, the platform has promoted citizen engagement and the desire to see a society built on tenets of compassion, justice and inclusivity.

There is a vibrant innovation and entrepreneurship ecosystem in **Kenya** facilitated through the establishment of a number of both public and private incubators, accelerators and technology hubs. This innovation ecosystem although growing is still immature and stands to benefit from greater support and strengthening. Growing but overlooked is the very significant role of the informal sector as a location of knowledge production, dissemination and impact. The informal sector has been key in recent innovations. It has supported mobile-based finance innovations like *M-Pesa, Airtel Money* to thrive including mobile apps like *iCow and M-Farm* designed to support small-scale farmers and the development of community cryptocurrencies in slums. However, there is very little support in public policy for strengthening formal-informal sector links. Further, the high cost of registration and high tax burden on small businesses actively discourages informal businesses from formalising, limiting opportunities such as financial access to catapult the sector.

University-industry partnerships have also emerged in addressing some of the SDGs. A number of lessons are derived from the case study on University-Industry linkages in different organizational settings in **Kenya**, focusing on JKUAT, a public university and Strathmore, a private university. While JKUAT was set up with a specific focus on smallholder agriculture and supporting local communities, partnering with devolved county governments on local development priorities, it has recently established the Sion Africa Centre for promoting indigenous, ethno-botanical knowledge. On the other hand, Strathmore University has tried to explicitly blend business and community interests through the various centres established. The Kenya Climate Innovation Centre, for example, has a strong focus on supporting SME's launching climate smart innovation as well as other relevant specialized centres focusing on issues related to sustainability such as the Energy Research Centre.

Innovation hubs, accelerators and incubators in **Tanzania** complement industrial knowledge needs but these hubs are largely externally funded through TANZICT (the Information Society and ICT Sector Development Project in Tanzania) and supported by the Government of Finland (Esselaar & Adam, 2013) and this tends to influence the direction of travel. The hubs e.g. 'Elimu Living Labs' do continue to support and link local and non-local knowledge production and impact including spin off activities addressing e.g. societal needs (Hooli et al., 2016). In **Rwanda**, there is now the emergence of private universities and think tanks, but these required further strengthening to allow them to have more influence in the future.

There are a significant number of novel initiatives and activities which drive social innovation, but also product and service innovation. These might contain disruptive models of innovation. Importantly they can include the potential to strengthen key knowledge system interactions and nurture a wider STI landscape that is conducive to SDG aligned outcomes.

In **Tanzania**, one example is the way training in the informal sector can lead to employment opportunities in the formal sector. This is illustrated by a case study that studied ***the impacts of innovations in the context of KS: looking at the case of Buni Innovation Hubs versus Tanzania Vocational Education Training Authority (VETA) Programmes***. The study revealed high absorption rates of these graduates in the formal sector (especially energy sector) including high employment rates in the fields such as electricity, gas, steam and air conditioning supply, construction, wholesale and retail trade, ICT, arts, entertainment and recreation. This has been supported by the recognition of practical experience in place of formal qualifications and entry requirements for courses - a route to an inclusive model of training. Also the introduction of the Skills Development Levy programme whereby the employers are required to pay for this levy and in return are granted 95% subsidy for sending their staff to vocational training has strengthened the linkage between formal and informal knowledge. Again, as demonstrated by another case study ***on Institutional innovations in agricultural technology outreach, a case of Sokoine University of Agriculture's Village Knowledge Centre*****,** formal and informal knowledge interactions create higher research-practice pathways through the active engagement of researchers in co-innovation. By way of example, as the village knowledge centres evolved and matured, they became a knowledge exchange for a diversity of topics beyond agriculture. Their earlier set mandate included promotion of technology and innovation relevant to smallholder farmers but have expanded to identify, negotiate and develop shared value opportunities that benefited smallholders and the private sector e.g. developing of milk production processing and marketing systems. Therefore, this form of engagement needs be valued. Other initiatives are emerging networks for example, TAI Tanzania,

https://www.facebook.com/taitanzania/ connecting development in communities. Founded as an unregistered initiative, it has promoted informal networking. SIDO, a government institution is also encouraging value addition for informal operators through a partnership where they provide space/shade and the informal worker could have a "formal environment" to work. Such initiatives need be nurtured, supported and scaled up within the Tanzanian KS environment.

Study question 3:
Using the practical concept, can we provide (b) identify new opportunities to strengthen the SDG impact of STI investments?

Yes particularly at the fringes of the formal STI environment

We observed significant informal sector knowledge activity in all three countries which were of high relevance to local communities and the SDGs but these are not mainstreamed, outside the normal STI conversations and as such, they are overlooked.

In **Rwanda**, formal-informal interactions are growing and continue to be publicly supported. One such example, is an initiative of inclusive health systems in Rwanda conducted through our case study ***bridging indigenous knowledge with sustainable development and inclusive health systems: The case of medicinal plants research and engaging traditional healers***. The initiative revealed the importance of informal knowledge sector who impacts largely formal systems. It has mobilised traditional health knowledge to contribute to a more accessible and relevant health system to reach many people who would otherwise not be able to access health services. It has demonstrated the importance that synergies between formality and informality through processes as regulation, creating opportunities for private sector investments and capacity building could help optimize the health systems and contribute to achieving outcomes. Investments in innovation hubs proliferating in the country have supported the development of technologies that support communities. Our case study on ***Understanding the impact of investments in development of innovation hubs and centres towards SDGs; the case of kLab and Fablab incubation centres*** demonstrated how these hubs have managed to train mentees in ideation and co-creation of technologies that can be embraced by communities to solve their day to day challenges. The mentees have further helped clarify technologies developed and subsequent intake of the young entrepreneurs who are individuals focusing on needs of the Rwanda people and solving communities' challenges through ICT. Previously clients taken on board have focused on role of technology in helping the government promote participatory governance, transparency and more effective public services for social and economic prosperity. Other initiatives that have supported community interactions include the Centre for Innovation and Technology transfer (CITT), which started as a vibrant hub for supporting linkages between community needs and university resources. It has since catalyzed a successful biogas project in prisons (Tigabu et al., 2015) aimed at reducing deforestation and enabled distribution of prototypes for agricultural processing equipment and has further contributed to the diffusion of policies for biogas more broadly (Tigabu et al., 2015).

5.4 Did our country stakeholder processes work?

Reference has been made throughout this report to the importance we attached to have a continuous engagement in the three countries by way of the processes outlined in Section 3.3 above. Great enthusiasm was encountered during the stakeholder engagements in all three countries which generated much insight, provided challenge to the conceptual approach and allowed the findings to be grounded. We deliberately set up structures e.g. the communities of practice that could provide a foundation for further work in the revisioning of future STI investment strategies. This pilot study has created an appetite for a different type of STI-related discussion; social capital that could be built upon.

The final engagement under this pilot study was the ground the overall findings with the country teams and get their insights on practical activities that could form investment options in terms of how the country CoP might re-vision national STI polices for SDG-aligned impact. The findings of this pilot study were well received, and Table 4 below summarises the feedback in terms of the areas where investment should be targeted.

Table 4. Stakeholder engagement - key areas considered important for future investments

Kenya	Tanzania	Rwanda
Four key areas identified namely: • facilitation of formal-informal interactions • investment in research and data for decision making; • investments in knowledge exchange platforms; • investments in knowledge intermediaries/champions and frameworks to support knowledge brokerage	Three key areas identified for new investments were: • support productive interactions between formal and informal sectors and knowledge; • investments in data collection for decision-making; • Support of research initiatives linking with end users.	Key areas identified for future investments were: • support knowledge production efforts between state and non-state actors. • Support for consultative platforms • Support universities to spur non R&D innovations; • Support more detailed diagnostic studies to establish impact of STI investments

Two highlighted areas for future investments that were common across all three countries – the need to strengthen formal-informal links and the need for investment in platforms that allowed knowledge to be exchanged particularly with end users. In Kenya it was considered important to support champions to drive the knowledge brokerage function. In both Kenya and Tanzania, the need to invest in research and data collection was highlighted which concurs with the wider macro analysis. Further support to the universities in Rwanda was seen as a key driver in particular capitalising on indigenous knowledge and the need for better impact evaluation was also highlighted.

The section below provides an overview narrative of the engagements across the three countries and an expansion on the practical interventions that could be supported in addressing the key areas for potential support in the future.

5.4.1 Overview of stakeholder engagement thoughts towards re-visioning STI policy in Kenya, Tanzania and Rwanda

While our study revealed that there are a number of funding initiatives that support development and delivery of STI interventions, stakeholders from the policy domain of STI in **Kenya** proposed the need for investments that support proper coordination of the various funding schemes that exist to target the informal sector. They called for the establishment of a body to oversee and coordinate these funds (Uwezo fund, youth fund, women enterprise fund) to address the main objective around supporting of the SMEs as well as the need for the establishment of a research coordination policy. Stakeholders also suggested establishing a glue fund within NRF, a fund to support the development of the informal sector, who often struggled to formalise due to tax burden that hinders their registration thus blocking access to certain funding sources. Current proposals by NRF include creating a commercialization fund to get research findings into usable products. Kenyan stakeholders emphasized the need for mentorship programmes steered by academia to support the *Juakali* sector not only to scale but also link them to formal processes. Four key areas were identified along with a series of policy-related insights that could be considered:

Facilitating formal informal interactions through the mechanisms outlined below:

- *focus new investments on linking the formal and informal sector where specific opportunities exist to align with the SDGs. Also, in the process, focus on building and sustaining these capacities and capabilities.*
- *set up a business investment fund specifically targeting informal sector innovation-led business opportunities including government oversight body to oversee investments such investments.*
- *indigenous knowledge resource centres are valuable, but pretty isolated. Examination of how to leverage knowledge repositories for actual impact should be undertaken and an assessment of how they can influence research agendas in the main stream.*

- *investments in the informal sector should make deliberate attempts to understand and invest in the key enablers required to facilitate the informal linkages.*

Investment in research and data for decision making;

- *more analytical studies that provides detailed data and information regarding these incubations/innovation hubs to attract possible investments and partnerships.*
- *invest in strengthening efforts in the existing accountability measures for tracing /tracking investments returns in various sectors. Invest in data or platforms within national agencies where current or previous investments and progress towards some of these investments can be viewed.*

Investments in knowledge exchange platforms

- *investments in knowledge exchange platforms are a potentially powerful way of leveraging impact from research investments. However complementary investments need to be made in governance structures to ensure inclusiveness of process and direction.*

Investments in knowledge intermediaries/champions and frameworks to support knowledge brokerage

- *invest in knowledge brokerage including enhancing their capabilities and support over a long period of time. There is potential to replicate the research into use model of promoting stakeholder conversations to enhance research use across* other *SDG areas but with proper coordination and building more consultative platforms for learning and knowledge use.*

In **Tanzania**, advice included closer engagement of COSTECH playing an advisory role, which was actioned. These consultations also informed the case study selection where there was need to explore case studies with technological innovations as the norm has been the seclusion of social innovations. Although, we report positive engagement processes, there were dissimilarities in the various stakeholders' views. For example, the policy makers would like to see more investments in the funding structures of the STI system in terms of coordination agencies. While these were plausible, these majorly emphasised traditional innovation systems thinking. A number of them were equally sceptic particularly of academia whose ideas revolved around formal process of driving knowledge production. But through further consultations by the same stakeholders in academia and through cases studies, examples of STI investments that are delivering for SDGs were explored. From the discussions we it considered a challenging task to initiate STI initiatives that contribute to SDGs, but this would certainly be aided through continued stakeholder engagements and consultations. This requires building momentum in the country while addressing some of the political economy issues. Investment priorities as identified by the stakeholders are discussed in the insights below.

Support productive interactions between formal and informal sectors and knowledge.

- *Need to explore such initiatives and facilitate their interactions with the formal sectors*
- *Establish or strengthen existing knowledge exchange networks/centers that seek to find and share solutions to community development challenges. In doing so consider how they can be effectively integrated and leveraged to contribute to transformative knowledge system development.*

Support of research initiatives linking with end users

- *Explore how village knowledge centers can be replicated. But the design should evolve so that the agenda is not a scientific driven agenda but that which is mutually beneficial to the local communities.*
- *Introduce information centres in Vocational Education and Training Institutions to facilitate formal informal interactions & ensure such initiatives are supported and scaled up in Tanzania KS environment.*
- *Also, the institution VETA should consider expanding and upgrading capacity to absorb more than the current intake which stands at 30% through capacity and capability building of the trainers, acquisition of learning infrastructure and equipment.*

Investments in data collection for decision making

- With specific reference to the innovation hubs explored, a *more detailed diagnostic of this ecosystem is required to generate quantifiable data and more in-depth information about their organization, business models, gaps and their impacts. This will enable; (i) more appropriate investments strategies including programs that need to be supported besides ICT (ii) exploration of a management/hosting model that reduces bureaucracy to encourage private sector linkages and more collaboration with*

formal and informal local institutions (iv) explore opportunities to target start-ups with inclusive and sustainability business models.

In **Rwanda**, while stakeholders echoed that most initiatives in Rwanda are state-led, they affirmed that there are a number of other on-going initiatives supported by private sector players. For example, the initiative of bridging traditional healers to formal health systems is also implemented in collaboration with a private university (INES-Ruhengeri) among other partners as commission for UNESCO, the University of Rwanda as well as NIRDA. Stakeholders also emphasized data gaps in KS and innovation ecosystems in Rwanda as a challenge that needs to be addressed if STI is to deliver for SDGs. Data management (and by whom) is still a concern and a key challenge even for policy coordination. Therefore investments in a national database that supports cross sectoral policy coordination and the understanding of all the sectors of the economy is needed. Furthermore, data is needed on investments in engineering sciences' research including performance of innovation hubs supported by the private sector.

Limited role of non-state actors producing knowledge

- *Need for Investments to support knowledge production efforts between state and non-state actors.*
- *Focus on inclusion of an array of informal governance actors in STI planning and implementation could help balance state-led tendencies and the reliance on private industry delivery pathways.*
- *need to strengthen more consultative platforms with the informal actors.*

Support for universities in Rwanda

- *In addition to contributing to R&D (STI)-based innovation (from commercialization of knowledge output), universities in Rwanda should be supported to spur non-R&D based innovations (from indigenous knowledge) as well as non-commercial innovation (e.g. organizational or institutional innovations, collaborations amongst departments/researchers within one institution/field of research).*

Impact of STI investments

- *Need for a more detailed diagnostic study to establish impact of such initiatives to encourage wider investments and scale.*

Section 6 Reflections

This section reflects on the relevance, usefulness, feasibility and limitations of the practical KSI conceptual framework developed and applied by this study. Reflection of this sort is a way of stress testing the approach used and defining a practical concept and additional developments that may need to be made to it. This section leads to the recommendations from the study which are presented in the final section. This pilot study sought to address three key questions:

1. Can we develop a practical concept that provides fresh explanations of the ability of STI investment to contribute to balanced growth impact i.e. aligned to the SDG agenda of inclusive and sustainable and smart growth?;
2. Using the practical concept, can we provide (a) an explanation and evidence of what is working or not in Kenya, Tanzania and Rwanda? And (b) identify new opportunities to strengthen the SDG impact of STI investments?;
3. Can we develop an economics approach that can identify the impact and alignment of the investments in the target countries and what are the feasibility considerations and limitations of this work?

The KSI conceptual framework, albeit tested on a pilot scale, **can help adapt existing STI framings (and associated investment priorities) to contemporary sustainable development challenges.** During the course of this project we ensured that we held a number of stakeholder engagement events/processes e.g. awareness workshops, forming communities of practice and advisory groups. These engagements were invaluable in ground truthing the KSI approach. One of the challenges we faced was that the KSI approach was viewed by some stakeholders as a more complicated version of innovation systems or innovation ecosystems perspectives, or as in competition with them. This was not the intention. Rather it was to arrive at a clearer picture of the relevance of existing STI capabilities to the sustainable development agenda. Thus, we sought to cast light on the priorities for adapting and linking dominant STI frameworks (research systems, innovation systems) such that the focus of attention was on sustainable development. The need for this is evidenced by our review of country level STI policy settings. Thus, this work argues that the KSI conceptual framework is not a substitute for existing policy and investment frameworks, rather it is a way of bringing these perspectives up to date by:

(i) Making explicit the relationship between STI capacity and practice with desirable outcomes, specifically balanced growth;
(ii) Making explicit the value of a range knowledge and innovation activity not normally considered in STI strategies;
(iii) Making explicit the importance of building connections between different domains of activity.

For example, in the case of Rwanda, where there is a robust STI strategy focusing on strengthening R&D capability and building links between public research and the private sector to build a knowledge economy. However, our analysis suggests that incentives to direct these capacities towards inclusion and sustainability are largely missing despite that articulation of these as part national policy. This holds true to varying degrees in the other countries studied. Here our KSI approach can be helpful in highlighting emerging and missing connections between different areas of knowledge related activity and realising the potential of a very promising STI strategy.

The deliberate engagement processes provided clear evidence that **there is an appetite for a different STI conversation in East Africa.** The stakeholder engagement processes revealed that many in the policy and development fields share concerns about current patterns of STI investment. This was evidenced by recurrent themes in these discussions about: weak translation of research outputs into practical use and impact; long term support to innovation that has failed to spread; neglected areas of innovation, particularly that relating to informal sector activity, such as the informal engineering sector in Kenya, traditional medicine and examples of promising innovation apparently over looked (e.g. the emergence of crypto currencies in Nairobi slums); and the need to assess STI capability in relation to national challenges rather than international standards. This was also accompanied by more familiar STI themes of underinvestment in R&D and gaps in science capability and capacity. The observation here is that this project has correctly asserted that a different STI conversation and revisioning is needed, would be welcomed and provides a foundation to build upon.

The different forms of analysis can tell a new story about STI patterns and performance. As can be seen in the previous sections, the use of quantitative and qualitative analytical methods and different lines of enquiry at

macro (economic data), meso (country mapping) and micro (case study) levels allows us to develop a new story about STI patterns and performance.

- The macro work helped explain that the different contributions of R&D to GDP in the three target countries is associated with the characteristics of the KS in each – some performing better, some performing worse. It also revealed the misalignment of research investments with the SDG and the way foreign funding can distort this.
- The meso country reviews not only revealed the limitations of current dominant STI policy perspective for the SDGs, but also revealed the enormous diversity of STI activity that is SDG facing; this is often hidden in modest sized projects and interventions which are disconnected from the mainstream STI policy narrative. The country reviews also helped highlight some of the generic STI challenges being encountered e.g. poor research uptake, weak research private sector linkages, limited attention to the informal sector and, critically, a very weak tradition of evaluation and documentation of results and lessons from specific STI investments.
- The micro level case studies looked deeper into novel innovation initiatives. The fact that stakeholder engagement processes could point to numerous examples to choose from, evidences that both different sorts of investments are being made and that there are many "positive deviant" outliers that could be built up to drive innovations for sustainable development. But the case study work also revealed another side to this story. It suggested many of the new wave of STI investments and priorities such business incubation and innovation hubs and the emphasis on supporting innovation at the public research-private sector interface had shortcomings. For example, the public private sector partnership model of Strathmore University, while highly successful in driving innovation was failing to target inclusive and sustainability business offerings as there were few incentives to do so. Innovation hubs and knowledge sharing platforms tended to perpetuate the research to commercialisation pipeline and did not create opportunities to respond to wider community needs or mobilise different sources of knowledge. There was also questions about how these sorts of initiatives could be sustainably funded beyond projects; for example, efforts to regulate the traditional healers' sector in Rwanda became a double-edged sword of empowerment and control. The case studies also revealed that for many of these novel and well-conceived innovation investments there was lack of capability to design and implement them effectively and only a partial understanding of their intended purpose in the larger innovation capacity effort. This was particularly so in more traditional research and development organisations. Overall, the story from the micro level work was that many well-meaning innovation support investments lack a specific framing that would target them explicitly on inclusion and sustainability and that there are many second order issues (such a capability and capacity building) that need to be tackled to leverage existing novel STI arrangements for sustainable development.

As evidenced by this study there were **limits to existing macro analytical tools and data sets and opportunities to address this.** With existing macro data presented in Section 3 above, it is possible to capture only limited components of the KS and even less interactions between these components. This in turn limits what can be said about the relationship between investments in the capacity of KS and economic and social returns to these investments. There are a number of issues that can be highlighted here including data availability, the complex non-linear relations, the measurement of inputs and of outputs. There is also the theoretical assumptions about how the inputs are related to outputs to consider. This compounds the challenge acknowledged earlier of establishing the impact relationship between R&D investment and economic impact that arises; because of the complexity of interconnections, practices, processes and drivers that mediate the way research derived knowledge is translated into innovation and impact. As an exercise in testing the feasibility of macro-economic analysis through a KS lens, this work reveals an important data obstacle. On the one hand a KS lens tries to reveal a wider set of knowledge related activity (informal as well as information knowledge production and use) processes (networks, partnerships and platforms) and drivers (social, political and market). But on the other hand, existing macro data sets have been used for a much narrower set of STI input and output measures and indicators. One relevant outcome of the current study is to pave the way for future research to improve the measurement of the KS, to analyse the interactions between different components, and relation with different socio-economic outcomes. Investments in the development of new data sets e.g. in finer analysis on the research system in order to reveal the full scope and impact of knowledge and innovation related activity through a KS lens would make a critical contribution to policy makers efforts to develop STI strategies that better align to the sustainable development agenda.

Section 7 Recommendations

In moving forward it is important to stress that this study does not advocate that existing approaches such as that of research systems and/or innovation systems are no longer useful ways of framing STI investment. Far from it. This study argues the proposed KS concept could add value to decision makers' understanding of the STI landscape and inform additional and different sets of STI investment that better leverage SDGs relevant outcomes.

The findings from this study allow a series of recommendations to be made focussed upon (a) new types of investment opportunity to leverage SDG-aligned outcomes and (b) further development and application of the practical KSI concept.

7.1 Recommendations for new types of investments

It is important to stress here that significant STI analysis in the target countries has already been undertaken and that these point to many issues related to the thematic focus and prioritisation of STI investments as well as issues related to the functionality of innovation systems. This study does not repeat the findings of these studies (patterns of R&D investment etc) but focuses on novel investment opportunities that arise from the additionality of the KSI approach.

- **Strengthen and prioritise STI investments in knowledge generation, translation, brokerage by intermediary institutions and platforms e.g. innovation hubs, communities of practice in addition to governance and accountability frameworks that ensure STI investments aligned to SDGs and broader national commitments**. There is already significant interest and investment in a range of mechanisms that link research to private sector and other research users, often seeking to catalyse entrepreneurial-led innovation but also social and policy innovation. The need to strengthen this intermediary brokerage function is evident in stakeholder dialogues in all three countries. Existing approaches take a number of forms such as innovation hubs, knowledge exchange platforms and other forms of knowledge brokering. While there is anecdotal evidence that these are delivering results there is an insufficient evidence base to judge what is working well and particularly what is working well in terms of delivery SDG relevant outcomes. A suggested starting point would be to build on this promising start and explore how these approaches could be strengthened, better aligned to SDG impacts and how patterns of governance and financing could be developed to maintain relevance and suitability.

- **Ensure that future investments leverage better linkages and actively promote partnerships between formal and informal sectors**. This study has revealed significant informal sector knowledge and innovation activity that is highly aligned to community needs and is a critical source of employment, income, products and services for poor people. In conclusion, there a clear case for devising frameworks rooted in an understanding of informal sector innovations as an important part of the STI landscape and the economy as whole. However, analytical and creative thinking is required to find ways of leveraging this to improve the orientation of innovation investment towards inclusive and sustainable development outcomes. We suggest that activities that specifically target informal – formal sector linkages are worthy of attention. There are many opportunities, for example, linking informal and formal research and innovation activities; providing financing for informal sector business that are creating products and services for poor communities that have potential to scale. Our study cautions against formalising informal sector activity e.g. the case of the traditional healers in Rwanda. Rather it stresses the potential for strengthening the innovation potential of this activity through R&D support, entrepreneurial development and financing. The formal sector could also gain much from better links to the informal sector, for example new research questions associated with reverse engineering of low cost products (a common strategy in the informal sector) and as a source of business and product models that the formal business sector is better placed to scale.

- **Work to make sure that STI investments are inclusive and incorporate broader views and perspectives and leverage a range of diagnostic tools/approaches when making policy and investment decisions**. There is a real opportunity to **build on the social capital created** by this pilot study. In all three countries, it was evident that there is much enthusiasm to engage in a new STI policy

related debate focussed on societal need. New investments for the region could build on this promising start by creating a focal point and convener of a more widely framed conservation about current STI performance and visioning for the future. If this achieves nothing else, it will deliver ideas on alternate pathways to SDG impact from STI investments at a time when it is becoming increasingly clear that established patterns of investment are struggling to achieve their promise.

7.2 Recommendations for taking the practical knowledge system forward

This pilot study has identified the potential of a practical KS approach and also the limitations in terms of what can be done with current data sets. The following recommendations aim to provide practical steps in taking the KS concept forward and/or addressing limitations observed during this work.

- **Further testing the approach in strategic planning exercises.** To seek out stakeholder-led processes and adopt the KS concept in current and emerging strategy and planning initiatives. The idea would be to undertake a diagnostic process in which learning across a diversity of KS perspectives, actors and initiatives casts light on barriers and enablers for STI investments to contribute to sustainable growth needs in particular settings. Strategy to date could be tested against this backdrop and this would be relevant to the building and supporting of the FCDO research and innovation hubs and to science granting council initiatives. For example:
    a) Test the approach by mapping synergies in existing investment portfolios and exploring with stakeholders the wider set of overlooked activities that might have relevance at different points in STI visioning, planning and implementation processes. This is a critical next step in testing ways of building new connections and synergies across the STI landscape that can have transformative effects on patterns of STI investment and outcomes.

- **Build on the social capital created by this pilot study**. Based upon the enthusiasm observed, in all three countries, during this study it is evident that there is much willingness to engage in a new STI policy related debate focussed on societal need. New investments for the region could build on this promising start by creating a focal point and convener of a more widely framed conservation about current STI performance and visioning for the future. If this achieves nothing else, it will deliver ideas on alternate pathways to SDG impact from STI investments at a time when it is becoming increasingly clear that established patterns of investment are struggling to achieve their promise.

- **Invest in research on STI metrics.** Our study highlights major limitations regarding the findings that can be derived from existing datasets (the same datasets that are clearly being used to inform current decision making). There is a need for a major investment in constructing new indicators, using available sources of unstructured data, and in collecting new data integrating survey and administrative data. In terms of providing practical recommendations and going beyond the usual type of recommendations of building statistical offices to collect and process macro data – comparable across countries, the following could be considered in future research projects:
    a) Redo the analysis at the micro level for each country using, where available, data on firms, workers, and farmers. Data on firms is emerging, such as for example the 2016 National Micro, Small And Medium Establishment (MSME) Survey in Kenya. There are a couple of challenges, firstly, such datasets are usually difficult to access (or even to find) and secondly, they rarely provide a follow up, which is really what is needed in order to study dynamic relations such as those that involve innovation;
    b) Collect data on the informal sector, which accounts for around 70% of African employment (Stuart et. al. 2018) and which is an engine of innovation (Kraemer-Mbula and Wunsch-Vincent, 2016). Some experiments in South Africa, Ghana (Avenyo, 2018), Kenya (see MSME above) and Nigeria are already underway but much more needs to be done (Charmes, Gault, Wunsch-Vincent, 2016), especially to build longitudinal data;
    c) Harmonising available micro data from households, which also contain information on education, production, employment, and investment in small and informal activities;
    d) Explore collection of unstructured digital traces, that can provide a lot of information on different components of the KS at a very fine level of granularity, across sectors, and subnational geographies (Eurito, 2018). For example financial and bank transactions (Carvalho

et. al. 2020 and Fajgelbaum et. al. 2020), phone calls (Blumenstock, Cadamuro and On, 2015), access to youtube, day satellite images (Neal, et al, 2016);
e) Collect better measures of the quality of education, rather than quantity; and longitudinal data on skills and employability, to be able to track how students enter the job market and move across jobs;
f) Address the critique that using scientific publications in WoS and Scopus (as we did) as a proxy for scientific outputs in African contexts leaves out research from authors in these countries that does not appear in these two major platforms. Creating an indexing system including all scientific journals from African countries, like for example Scielo in Latin America;
g) Collect better data on funding, including their source, recipient and use, in line with data systematization effort available in specific originations/sectors (e.g. the US National Institute of Health), in growing repositories such as Dimensions and Researchfish, and ongoing work by the UK Collaborative on Development Research (UKCDR) to map ODA research funding.
h) Focus on field experiments. Current efforts from IPA and J-Pal and the Word Bank focus on management practices. The Growth Lab at Nesta is promoting field experiments on innovation and innovation policies, but mainly in OECD countries. Designing robust experiments on innovation, given the complex relations that is behind any innovative process is complicated, but feasible. There is ample space to think about field experiments to study innovation, capabilities and the KS in LMICs. Members of the project team have discussed a number of ideas with Nesta and the World Bank.

- **Invest in robust and continuous impact evaluation of STI investment and use this to guide investments and policy decisions.** This study highlights significant gaps in the data available and expresses caution on the limits to the existing macro analytical tools as a means to inform decision-making. This study also highlights there is little in-built evaluation and learning taking place to inform STI planning decisions in the target countries in East Africa. In particular there is a need for ex-ante, real time and ex-post M&E strategies and frameworks, along with appropriate micro, meso and macro data sets, to adequately assess STI systems, processes and outcomes in relation to environmental, social and economic goals. In terms of practical next steps to set the foundation for this could include:
    a) A critical assessment of the adequacy of existing metrics and evaluation tools with a view to defining feasible set of metrics and tools better adapted to monitoring, evaluation and learning STI impacts through a knowledge system and SDG lens;
    b) Explore the feasibility of building data/information centres/platforms on STI investments and outcomes – drawing from both state and non-state actors- to enhance access and generation of meaningful indicators to measure impact across a range of social, environmental and social objectives.

References

Arocena, R., Goransson, B. and Sutz, J. 2018. Developmental Universities in Inclusive Knowledge Systems – Alternatives for knowledge democratization in the global South. Palgrave Books.

Avengo, E. 2018. Informal sector innovation in Ghana: data set and descriptive analysis. UNI-MERIOT Working paper. https://www.merit.unu.edu/publications/working-papers/abstract/?id=7864

Bell, M. and Pavitt, K. 1993. "Technological Accumulation and Industrial Growth: Contrast Between Developed and Developing Countries." *Industrial and Corporate Change* 2 (2): 157–210.

Blumenstock, J., Cadamuro, G. and On, R. 2015. "Predicting Poverty and Wealth from Mobile Phone Metadata." *Science* 350 (6264): 1073–76. https://doi.org/10.1126/SCIENCE.AAC4420.

Carvalho, V, Juan R. Garcia, S. Hansen, A. Ortiz, T. Rodrigo, and J. V. R. More. 2020. "Tracking the COVID-19 Crisis with High-Resolution Transaction Data." *Cambridge Working Papers in Economics*. Faculty of Economics, University of Cambridge.

Charmes, J., Gault, F. and Wunsch-Vincent, S. 2016. "Formulating an Agenda for the Measurement of Innovation in the Informal Economy." In *The Informal Economy in Developing Nations: Hidden Engine of Innovation?*, edited by Erika Kraemer-Mbula and Sacha Wunsch-Vincent, 336-. Cambridge University Press.

Chataway, J. and Daniels, C. 2020. Chapter 3 The Republic of Science meets the Republics of Somewhere: Embedding scientific excellence in sub-Saharan Africa
In Transforming Research Excellence. New ideas from the Global South
Edited by Erika Kraemer-Mbula, Robert Tijssen, Matthew Wallace and Robert McLean
https://library.oapen.org/bitstream/handle/20.500.12657/23441/AMT%20Research%20Excellence%20FINAL%20WEB%2002012020.pdf?sequence=1#page=47

Chataway, J., Daniels, C., Kanger, L., Ramirez, M., Schot, J. and Steinmueller, E. 2017.
Developing and enacting Transformative Innovation Policy: A Comparative Study. 8th International Sustainability Transitions Conference June 2017 Gothenburg, Sweden.

Chataway, J., Dobson, C., Daniels, C., Byrne, R., Hanlin, R. and Tigabu, A. 2019. Science Granting Councils in Sub-Saharan Africa: Trends and tensions, *Science and Public Policy*, **Volume 46**, Issue 4, August 2019, Pages 620-631, https://doi.org/10.1093/scipol/scz007

Chataway, J., Ochieng, C., Byrne, R., Daniels, C., Dobson, C., Hanlin, R., Hopkins, M. and Tigabu. 2017. Case studies of the political economy of science granting councils in sub-Saharan Africa. Report for the Science Granting Councils Initiative.

Ciarli, T., Coad, A. and Rafols, I. 2013. "Quantitative Analysis of Technology Futures.
Part 2: Conceptual Framework for Positioning FTA Techniques in Policy Appraisal." Brighton.

Cirera, X. and Maloney, W.F. 2017. The innovation paradox: Developing-country capabilities and the unrealized promise of technological catch-up. Washington D.C., World Bank, doi:10.1596/978-1-4648-1160-9.License: Creative Commons Attribution CC BY 3.0 IGO

Confraria, H. and Wang, L. 2020. Medical research versus disease burden in Africa. Research Policy 49 (3). https://doi.org/10.1016/j.respol.2019.103916

Cozzens, S. and Sutz, J. 2014. Innovation in informal settings: reflections and proposals for a research agenda. Innovation and Development 4(1) 5-31

Daniels, C. 2020. Transformative Innovation Policy Africa Hub Exploratory. Final Technical Report. https://idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/59142/IDL-59142.pdf

Daniels et. al. 2020. Updating the Case studies of the Political Economy of Science Granting Councils in Sub-Saharan Africa. Forthcoming. See http://www.sussex.ac.uk/spru/research/projects/political-economy

Davies, E., Lähde, K., McGinty, D., & Rahaim, S. 2018. *Investing in social innovation and technology in Tanzania*. Esselaar, S., & Adam, L. 2013. What is happening in ICT in Tanzania? In *Evidence for ICT Policy Action* (Issue 11). https://doi.org/10.1080/00396331003764637

Eurito. 2018. Literature review report: The role of data in the R & I policy cycle. Retrieved from https://www.nesta.org.uk/project/eurito/

Fajgelbaum, Pablo, Amit Khandelwal, Wookun Kim, Cristiano Mantovani, and Edouard Schaal. 2020. "Optimal Lockdown in a Commuting Network." Working Paper Series. https://doi.org/10.3386/w27441.

FEI. 2016. *Doing transdisciplinary research : lessons from the front line*.

Fre, Z. 2018. Knowledge sovereignty among African cattle herders. UCL Press. See https://library.oapen.org/handle/20.500.12657/29683

Freeman, C. 1987. *Technology Policy and Economic Performance: Lessons from Japan*. London: Pinter.

Frost, A., Hall, A., Marshall, F., Atela, J., Ndege, N., Ciarli, T., Shee, A. Confraria, H., Dolley, J. and Chataway, J. 2019. *Understanding knowledge systems and what works to promote science technology and innovation in Kenya, Tanzania and Rwanda.* In: 2019 Global Development Conference. Knowledge for Sustainable Development: the Research-Policy Nexus. Global Development Network. (In Press) https://gala.gre.ac.uk/id/eprint/25863/

Gault, F. (ed) Edward Elgar. 2013. Handbook of Innovation indicators and measurement

Gibbons, M., Camille L., Helga N., Schwartzman, S., Scott, P., and Trow, M. 1994. *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*. SAGE Publications.

Gicharu, S. 2018. *To make TVET courses attractive to youth again, revamp system*. https://www.nation.co.ke/oped/opinion/To-make-TVET-courses-attractive-to-youth-again--revamp-system/440808-4582822-162c7fz/index.html

Griliches, Z. 1979. "Issues in assessing the contribution of R&D to productivity growth.", Bell Journal of Economics, 10(1): 92– 116.

Hall, B. H., Mairesse, J. and Mohnen, P. 2010. "Measuring the Returns to R&D." NBER Working Paper No. 15622, National Bureau of Economic Research, Cambridge, MA.

Hall, B.H., 2020. Patents, innovation and development, National Bureau of Economic Research. doi:10.1017/CBO9781107415324.004

Haskel, J. and Wallis, G. 2013. "Public support for innovation, intangible investment and productivity growth in the UK market sector." Economics Letters. 119(2):195–198.

Hooli, L., Jauhiainen, J. S., & Lähde, K. 2016. Living labs and knowledge creation in developing countries: Living labs as a tool for socio-economic resilience in Tanzania. *African Journal of Science, Technology, Innovation and Development*, *8*(1), 61–70. https://doi.org/10.1080/20421338.2015.1132534

Jerven, Morten. 2013. *Poor Numbers – How We Are Misled by African Development Statistics and What to Do About It*. Cornell University Press. https://doi.org/10.5771/0506-7286-2013-3-336

Jones, C. I., and Williams, J.C. 1998. "Measuring the Social Return to R&D." Quarterly Journal of Economics 113 (4): 1119–35.

Kipkirui, L. 2018. *Fit for purpose TVETS best bet for Kenya's push to industrialise.*

https://www.standardmedia.co.ke/article/2001287251/fit-for-purpose-tvets-best-bet-for-kenya-s-push-to-industrialise

Kline, S. and Rosenberg, N. 1986. "An Overview of Innovation." In, Landau, R,. Washington, DC: National Academies Press. http://books.google.co.uk/books?id=-nT3zZRenrUC.

Kraemer-Mbula, Erika, and Sacha Wunsch-Vincent. 2016. *The Informal Economy in Developing Nations : Hidden Engine of Innovation?* Cambridge University Press. http://www.cambridge.org/gb/academic/subjects/management/entrepreneurship-and-innovation/informal-economy-developing-nations-hidden-engine-innovation?format=HB#wVMtRcSZLJ7yDWXg.97

Kraemer-Mbulla, E., Tijssen, R., Wallace.M. and McLean, R. 2020. Transforming research excellence: New ideas from the global South. ISBN 978-1-928502-06-7 see https://www.africanminds.co.za/transforming-research-excellence-new-ideas-from-the-global-south/

Kumar, H. and Bhaduri, S., 2014. Jugaadto grassroot innovations: understanding the landscape of the informal sector innovations in India. *African Journal of Science, Technology, Innovation and Development*, 6(1), pp.13-22.

Lebel, J. and McLean, R. 2020. Research Quality Plus: Another way is possible. In Transforming research excellence: New ideas from the global South. ISBN 978-1-928502-06-7 see https://www.africanminds.co.za/transforming-research-excellence-new-ideas-from-the-global-south/

Links, A. L. M., Hart, T. and Jacobs, P. (2014) 'The dynamics of local innovations among formal and informal enterprises: Stories from rural South Africa', *African Journal of Science, Technology, Innovation and Development*. doi: 10.1080/20421338.2014.940168

Links, A., Hart, T. and Jacobs, P., 2014. The dynamics of local innovations among formal and informal enterprises: Stories from rural South Africa. *African Journal of Science, Technology, Innovation and Development*, 6(3), pp.175-184.

Love, I., Zicchino, L., 2006. Financial development and dynamic investment behaviour: evidence from panel VAR. Q. Rev. Econ. Finance 46 (2), 190–210

Lundvall, Bengt-Ake. 1992. *National Systems of Innovation: An Analytical Framework.* London: Pinter.

Muchi, M., Bhaduri, S., Baskaran, A. and Ahmad Sheikh, F. (Eds). 2016. Informal Sector Innovations: Insights from the global south. London: Routledge. ISBN 13-976-1-138-94352-0

Mutapi, Francisca. 2019. "Africa Should Set Its Own Health-Research Agenda." Nature 575 (28 Novemberr): 567. https://doi.org/10.4135/9781412971959.n413.

Neal, J., Burke, M. , Xie, M., Davis, W.M., Lobell, D. and Ermon, S.. 2016. "Combining Satellite Imagery and Machine Learning to Predict Poverty." *Science* 353 (6301): 790–94. https://doi.org/10.1126/science.aaf7894.

Nelson, Richard R. 1993. *National Innovation Systems: A Comparative Analysis*. New York: Oxford University Press.

Novitzky, Peter, Michael J Bernstein, Vincent Blok, Robert Braun, Tung Tung Chan, Wout Lamers, Anne Loeber, Ingeborg Meijer, Ralf Lindner, and Erich Griessler. 2020. "Improve Alignment of Research Policy and Societal Values." Science 369 (6499): 39–41. https://doi.org/10.1126/science.abb3415.

OECD 2015, Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development, The Measurement of Scientific, Technological and Innovation Activities, OECD Publishing, Paris, https://doi.org/10.1787/9789264239012-en

Onsongo, E. and Schot, J. 2017. Inclusive innovation and rapid sociotechnical transitions: The case of mobile money in Kenya. SPRU Working Paper Series 2017-07

Rafols, I, Ciarli, T., Van Zwanenberg, P. and Stirling, A. 2012. "Towards Indicators for 'Opening Up' Science and Technology Policy." In *Proceedings of 17th International Conference on Science and Technology Indicators*, edited by Éric Archambault, Yves Gingras, and Vincent Larivière, 2:675–82. Science-Metrix and OST. http://sticonference.org/Proceedings/vol2/Rafols_Towards_675.pdf

RICYT. 2001. *BOGOTA MANUAL: Standardisation of Indicators of Technological Innovation in Latin American and Caribbean Countries*. Retrieved from http://www.google.co.za/url?sa=t&rct=j&q=&esrc=s&source=web&cd=19&cad=rja&ved=0CGEQFjAIOAo&url=http://www.uis.unesco.org/Library/Documents/Bogota Manual_eng.pdf&ei=HPAZUYqxFOuW0QWcy4DADA&usg=AFQjCNG1TjbI_hfZRnPvpDFsiQlZIJ3gFw&bvm=bv.42261806,d.d2k

Salter, A. J. and Martin, B. R. 2001 "The economic benefits of publicly funded basic research: A critical review." Research Policy. 30(3): 509–532.

Schot, J. and Steinmueller, E. 2018. Three frames for innovation policy: R&D, systems of innovation and transformative change. Research Policy 47 (9) 1554-1567 https://www.sciencedirect.com/science/article/pii/S0048733318301987

Srinivas, S. and Sutz, J. 2008. Developing countries and innovation: Searching for a new analytical approach. Technology in Society 30 129-140 https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1099492

Stirling, Andy. 2008. "'Opening Up' and 'Closing Down': Power, Participation, and Pluralism in the Social Appraisal of Technology." *Science, Technology & Human Values* 33 (2): 262–94. https://doi.org/10.1177/0162243907311265.

———. 2009. "Direction, Distribution and Diversity! Pluralising Progress in Innovation, Sustainability and Development." Brighton.

Stuart, E., Samman, E and Hunt, A. 2018. Informal is the new normal – Improving the lives of workers at risk of being left behind. ODI Working Paper 530. https://www.odi.org/sites/odi.org.uk/files/resource-documents/11993.pdf

Tigabu, A. D., Berkhout, F., & van Beukering, P. 2015. Technology innovation systems and technology diffusion: Adoption of bio-digestion in an emerging innovation system in Rwanda. *Technological Forecasting and Social Change*, *90*(PA), 318–330. https://doi.org/10.1016/j.techfore.2013.10.011

Tvedten, I., Byabagambi, A., Lindstrom, J. and Tedre, M. 2017. Evaluation of the Sida supported research capacity and higher education development program in Rwanda, 2013-2017

Wallace, Matthew L., and Ismael Rafols. 2015. "Research Portfolio Analysis in Science Policy: Moving from Financial Returns to Societal Benefits." *Minerva* 53 (2): 89–115. https://doi.org/10.1007/s11024-015-9271-8

Yegros-Yegros, Alfredo, Wouter van de Klippe, Maria Francisca Abad-Garcia, and Ismael Rafols. 2020. "Exploring Why Global Health Needs Are Unmet by Research Efforts: The Potential Influences of Geography, Industry and Publication Incentives." Health Research Policy and Systems 18 (1): 47. https://doi.org/10.1186/s12961-020-00560-6.

UNCTAD. 2019. *A Framework for Science, Technology and Innovation Policy Reviews: Harnessing Innovation for Sustainable Development*. United Nations Conference on Trade and Development. http://unctad.org/en/Docs/dtlstict2011d7_en.pdf

Annex 1 Conceptual Literature review

Conceptual Literature Review for FCDO Knowledge Systems project

Executive summary
The literature review has highlighted several different approaches to various aspects of knowledge systems. These approaches rarely define knowledge systems explicitly but imply different goals, types of innovation and sets of actors as central to knowledge production and use. Conventional innovation systems literature provides insight on how to support knowledge production for market-led firm-based product and process innovation. Critiques of its application to developing countries increasingly emphasise the need for government intervention to broaden access to innovation processes to include informal actors and the poor and also to shift the emphasis of knowledge systems towards social goals. Innovation is re-defined as new ways of solving problems rather than new-to-market products or processes. Focusing more specifically on engagement with communities, literature on transdisciplinary development research is beginning to view knowledge systems more as diverse networks of actors involved, not just in shaping research problems or applying solution-oriented knowledge, but also forming politically engaged alliances. Innovation thus includes not just new technologies and processes, but also new institutions, practices and organisational forms. 'Newness' is locally specific and the environmental, economic and social goals of knowledge production are recognised as up for negotiation, plural and always open to revision. The broad and rapidly growing literature on sustainability transitions helps to highlight the potential role of multiple knowledge systems in co-ordinating large-scale long-term transitions while also supporting bottom-up, niche innovations. Each literature brings into focus a different aspect of knowledge systems while obscuring other equally important aspects. Investments and interventions guided by just one approach will tend to be biased and flawed. The challenge is to link these ideas together into a more integrated vision of knowledge systems that not only provide economic returns to public investment but are also responsive to the multiple social and environmental agendas of society. As a step towards this integrated concept we present a diagram of different perspectives on knowledge systems alongside a typology of knowledge systems and pathways for investment which will both inform the fieldwork and be further modified through reflection on empirical results.

1. Introduction
The need to invest in Science, Technology and Innovation (STI) capability in low and middle-income countries (LMIC) has long been recognised but there is limited action and investigation into how to do this and what works in LMIC contexts. A number of countries in Africa are setting their agendas for STI (e.g. Chataway et al., 2017) including commitments to the African Union (AU) Strategy of Africa 2024 (STISA-2024) and the AU Agenda 2063. However, these efforts are hampered by limited evidence on effective strategies for investment and intervention.
The period since WW2 has witnessed three major framings of innovation policy (Schot and Steinmueller, 2016). Extensive critique of the 'linear model of innovation' underpinned innovation systems analysis which has played a key role in informing innovation since the later 1980s. While innovation systems thinking has provided new insights about the relationship between science and innovation, it has been applied mainly to developed countries or rapidly industrialising contexts and does not reflect the reality in LMIC. For example, particularly in light of the socio-economic challenges facing LMIC, funding on the basis of merit and long-term gains from 'excellence' narrowly defined does not necessarily result in economic and social benefit for all (Chataway et al., 2007). More recently, it has been critiqued on the grounds that, while it has been helpful in identifying ways to increase the rate of innovation, it has had little to say about 'direction' (Leach et al., 2012; Stirling, 2009). Thus, much innovation systems analysis is of limited use in thinking about how to construct policy which fosters environmental sustainability as opposed to conventional trajectories which may be environmentally damaging. Innovation systems thinking has also not addressed the issue of how to construct more inclusive forms of innovation and other social goals. However, it seems clear that in order to maintain political support and the momentum which currently exists for funding research and innovation (UNESCO, 2015), science will need to contribute to short and medium term social and economic priorities in LMIC.
We argue that, in order to support national STI strategies and capabilities in LMIC with social, environmental and economic development goals in mind, a practical concept of knowledge systems is required. This conceptual literature review takes as its starting point the definition of knowledge systems outlined by Cornell et al. (2013): a knowledge system consists of "agents, practices and institutions that organize the production, transfer and use of knowledge." This definition provides a broader focus than many previous studies of R&D systems and innovation systems. While it includes the production and use of knowledge for innovation, the knowledge

system concept goes well beyond that to focus attention on the mobilisation of knowledge in the pursuit of multiple aspects of sustainability. We review a range of literatures on innovation and knowledge systems and draw out key insights relevant to LMIC contexts. These are brought together in an initial conceptual typology of knowledge systems and investment pathways.

The purpose of this conceptual literature review and typology is to explore knowledge systems through contrasting theoretical framings to draw out some key insights for developing a 'practical knowledge system concept'. The conceptual review provides a point of reference in an iterative process of analysis and reflection between the in-country literature reviews and fieldwork. The aim is to incorporate aspects of established international literatures with insights from the empirically focused in-country literature reviews to inform the priorities for interviews and other mapping activities. The fieldwork and in-country literature reviews will also be key steps in helping to develop and contextualise the practical knowledge system concept as it evolves throughout the project.

2. Innovation Systems

Innovation systems approaches, building on ideas first set out by Richard Nelson, Christopher Freeman, Bengt-Åke Lundvall, Pavel Pelikan and others in Dosi et al. (1988), emphasise firm-level learning and capabilities alongside a dynamic systems view of innovation to suggest the factors necessary for the industrial development of latecomer countries and firms (Freeman, 1995; Lundvall, 2010; Lundvall et al., 2002; Nelson, 1993). The impact narrative is that national and sectoral industrial, finance, education and STI policies can create conditions for domestic firms to upgrade their capabilities, incentivise their strategic behaviour, disrupt the activities of foreign incumbents in order to take advantage of windows of opportunity for domestic firms to gain technological leadership and capture market share (Lee and Malerba, 2017; Malerba, 2002; Viotti, 2002). Emphasis is placed on providing high quality human resources to firms, strengthening linkages across the innovation system (among firms and between firms and knowledge/technology providers), regulating foreign direct investment and funding firm-based R&D.

It is also argued that regional (sub-national) innovation systems in developing countries can function as specialised hubs connecting local clusters of firms to global value chains enabling them to rapidly move up the global value chain, gain new competencies and also shift to related industries (Chaminade and Vang, 2008). Policy-makers can therefore identify emerging regional innovation systems and design policies specifically targeted at strengthening them.

Another approach to strengthening innovation systems is through industrial clusters. Giuliani and Bell (2005) argue that knowledge systems operate within industrial clusters in which firms are expected to play different roles in the diffusion and exploitation of knowledge and the absorption of external knowledge depending on each firm's knowledge base, absorptive capacity and their 'cognitive distance' to one another and external sources of knowledge. Policies shouldn't focus on promoting spatial agglomeration but on increasing individual firm's knowledge bases and mechanisms to support relational connections between firms internal to and external to the cluster (e.g. through specialised knowledge workers) (Bell and Albu, 1999; Giuliani and Bell, 2005).

Bernardes and Albuquerque (2003) analyse statistical data for 120 countries to conclude that there is a shifting threshold level of scientific output (e.g. 150 scientific papers per million inhabitants in 1998 and increasing with time) "beyond which the efficiency in the use of scientific output by the technological sector increases". They argue that the poorest countries must focus on building scientific institutions particularly in priority sectors (health, agriculture, engineering) in order to increase absorptive capacity.

Comparing the drivers of long-term growth in multiple countries Lee and Kim (2009) suggests that in low-income countries economic growth can be enhanced by investment in secondary education and strengthening institutions, while in middle-income developing countries the focus should be on investing in improving and increasing participation in tertiary education and technology focused R&D. "the general finding that while secondary education and political institutions turn out to be important for lower-income countries, the policies facilitating technology development and higher education seem to be more effective in generating growth for upper middle- and high-income countries than for lower-income countries. The suggestion this seems to make is that policies aimed at growth should take into account the stage of development of countries concerned are in." (p. 545-6).

The innovation systems concept has been applied to developing country contexts to identify strengths and weaknesses in R&D systems, national innovation systems and STI policy (OECD, 2013; Padilla-Pérez and Gaudin, 2014; UN ECA, 2016; World Bank, 2010). The IDRC's Research on Knowledge Systems (RoKS) programme also adopted an Innovation Systems approach. For example, Wangwe et al (2004) evaluate the agricultural, health and industrial R&D systems in Tanzania. One of their conclusions is that the domination of foreign donor finance

in Tanzania's R&D systems exerts undue influence on research and development priorities while also creating instability and unpredictability which hinders the alignment of knowledge production and demand. They suggest that diversifying R&D funding to include national and private funding sources and prioritise greater participation in research agenda setting (e.g. through public-private partnerships) can help to address these issues.

Within the innovation systems literature the observation that high knowledge and skill intensity sectors grew most rapidly (in OECD countries) has led to the claim that this century is "characterized by increasing knowledge intensity in the production system" (Lundvall and Lorenz, 2012, p. 41). The new economy that is emerging is both 'knowledge-based' and a 'learning economy' (Foray and Lundvall, 1998; Lundvall and Johnson, 1994) in which rapid technical change is accompanied by the market selection of change-oriented firms and learning-oriented employees which in turn further drives innovation in a reinforcing cycle of change. To thrive in the new economy firms must successfully combine two modes of learning and innovation: production of global codified knowledge through R&D (STI learning) and the localised tacit know-how and organisational learning obtained through doing, using, and interacting (DUI).

Innovation policy must therefore promote both STI learning (including through the traditional investments in science and technology R&D and training scientists and engineers) and DUI learning through education policy to produce graduates with enhanced learning capacity and problem solving skills, provide continuous and life-long learning opportunities, maintain close connection between education and research in universities, promote social capital through greater equality of access to higher education. This policy approach needs to be complemented by measures to mitigate the inherent drive towards increasing inequality between high and low skilled workers that the learning economy implies because high social capital and trust are crucial to facilitating the interactions required to apply increasingly complex knowledge in the innovation process. The welfare state has a key role to play in this. (Lundvall and Lorenz, 2012). For related highly cited discussion of different types of knowledge see Cowan et al. (2000) and knowledge management systems see Alavi and Leidner (2001).

These literatures seem to share the same broad assumptions about knowledge and development which are relevant to developing our conceptualisation of knowledge systems. Knowledge is seen on the one hand as a resource for innovation and on the other as a means of upgrading firm capabilities and access to a skilled and adaptable workforce. A successful knowledge system would therefore be one which provides the necessary supply of knowledge, enhances firm-level capabilities (to absorb and apply that knowledge) and provide the institutional context to continue the learning process towards being able to innovate and compete in global markets. From this perspective patenting rates, firm market share and exports, education levels, in-house R&D levels are all indicators of a successful knowledge system.

3. Innovation for development

Innovation systems approaches have also been criticised for their bias towards developed and rapidly developing countries while neglecting the different kinds of challenges faced by low-income countries (Williams and Woodson, 2012). Discussing the relevance of innovation systems approaches to developing countries, Lundvall (2007) highlights the fact that these approaches have been more useful for explaining the evolution of innovation systems than system-building because of the largely unplanned and spontaneous nature of system evolution. Particularly in low-income countries, difficult living conditions constrain people's ability and willingness to engage in learning new capabilities and participating in innovation processes. An obvious policy strategy is to target the wider context of the innovation system in such a way as to reduce these difficulties by, for example, enhancing stability, basic living conditions and access to basic services. This should be done in tandem with efforts to enhance scientific and technological capabilities as well as institutional and organisational capabilities (Lundvall, 2007).

Srinivas and Sutz (2008) go further in their critique arguing for a reconceptualization of innovation appropriate to developing country contexts. They note that in advanced industrial economies technological innovation occurs in an ambience of abundance albeit with instances of scarcity of inputs to innovation which present a challenge to innovators (i.e. firms) but which can be overcome often through the application of abundant scientific resources. In industrializing countries, however, innovation faces an ambience of scarcity (i.e. lack of most of the resources for innovation). Scarcity-induced innovation (SII) is an important type of innovation relevant to understanding industrial development in underdeveloped countries. Types of scarcity in resources for innovation include:

1) Cognitive scarcity – search for solutions hampered by their absence in the metal landscape of innovator or by their non-applicability within local context or constraints;
2) Institutional/physical – lack of organizational, legal and technical resources;
3) Socio-economic – developing country problems ignored by 'innovative' advanced countries, policy bias, unaffordable solutions developed for advanced country contexts;

4) Scalability – SII tend to be encapsulated innovations which do not travel beyond their immediate context.

Examples of SII are:

- inventing alternative lower-cost or simpler scientific instruments and techniques to achieve the same purpose as sophisticated expensive ones;
- process innovations achieving similar outcomes through different ways from firms in industrialised countries;
- innovations targeted at resource-scarce users.

In this context, technological innovation is understood as involving the "synthesis of some kind of need with some kind of technical possibility" and the search for solutions occur within "technological universes". Scarcity conditions mean particular capacities are required: 1) problem solving capacities; 2) self-esteem (at individual and national level) as "fundamental to start a problem solving process"; 3) creativity; 4) policies to overcome the problem of 'invisibility' of such innovations; 5) collaborative planning processes to identify and prioritize localized innovations and lead to institutional change.

Foster and Heeks (2013) introduce the idea of the process of innofusion and the importance of micro-scale, semi-formal innofusion actors as crucial to enabling innovations to reach low-income markets. They use Fleck's (1993) notion of 'Innofusion' to refer to "the process of bringing inventions into use: as an innovated good or service is diffused, further innovations are required both to the good/service but also in surrounding social systems, and feedback from that diffusion leads to further innovation in the original good/service. Innovation and diffusion are thus inextricably intertwined." (Foster and Heeks, 2013, p. 335). Thus, they emphasise the role of users and marketing and sales micro-enterprises in generating new innovations/adaptations, propagating new uses for existing technologies and diffusing knowledge and innovations back to formal innovation system actors.

These critiques of innovation systems approaches emphasise the need to support not only the development of formal scientific and technological capabilities but also to strengthen informal problem-solving capabilities and facilitate interactions between formal innovation system actors and informal actors in marginalised communities. This allows for the proliferation of indigenous and informal innovations and also for formal innovations to be adapted and reshaped to suit local contexts and meet the needs of specific groups.

The call to reconceptualise innovation and knowledge systems around development goals has led some to argue for a widening of participation in 'knowledge politics'. The 'Direction, Distribution and Diversity' framing of the STEPS Centre (STEPS Centre, 2010; Stirling, 2009) argues for 'broadening out' and 'opening up' the social appraisal of "alternative trajectories in knowledge, innovation and development." (Stirling, 2009, p. 28). Different pathways of innovation involve different re-distributions of costs, benefits and power among different stakeholders and are therefore shaped by political choices and existing power relations resulting in closing down alternative directions in favour of reinforcing incumbent interests. Resisting this process requires designing policies to foster a diversity of innovation pathways – particularly those favoured by (and originating among) marginalised groups – and enhancing support for the social and organisational aspects of innovation (STEPS Centre, 2010). Increased collaboration in service provision and problem solving between universities and public actors is seen as crucial to this endeavour implying the need for a new type of 'developmental university' (Arocena et al., 2018).

This approach argues that sustainable human development requires the democratisation of 'advanced knowledge' – "the outputs of academic work and its applications" – which implies opening it to a wider "set of research problems and innovation projects that until now have been below its radar" and putting it "at the service of people until now underserved by it" (Arocena et al., 2018, pp. 1–2). Recognising knowledge as the "main resource in power relations" which perpetuate inequality and exclusion implies that the route to an inclusive innovation system is through generalising learning activities and spreading advanced knowledge throughout every sector of social and economic activity, particularly in favour of peripheral and excluded social groups (for example by fostering frugal innovation activities). The assumption is that universities should play a central role in this and therefore a new type of university is required which moves away from the increasingly dominant 'entrepreneurial' model towards a 'developmental university'. In terms of policy this means reframing innovation policies as social policies which promote forms of innovation "that connects knowledge production and use with increasing employability and services provision" (Arocena et al., 2018, p. 245) while also fostering capabilities for innovating under scarcity conditions and directed at solving problems for which solutions found in developed countries do not work or have not been looked for (see Srinivas and Sutz, 2008).

The role of the three missions of universities in this process are discussed: "teaching, research and cooperation for development with other institutions and collective actors." (Arocena et al., 2018, p. 167).

1. Teaching: making problem-based learning central (Gregersen, 2017) and including extension activities in curricula. Generalising access to Higher Education and life-long learning (similar to the Learning Economy view).
2. Research: oriented towards contributing knowledge and highly qualified researchers “to every socially valuable activity.” (Arocena et al., 2018, p. 168). While investment in science and high tech is necessary it also necessary to increase the knowledge intensity of primary production and low tech sectors (Arocena et al., 2018, p. 110 ff.). Research needs to be organised through increased interactions with economic, public sector and third sector organisations and most importantly with social groups who lack the market power to drive innovative solutions to their problems and who should be related to as agents not patients. Increasing interdisciplinarity is also necessary with a higher value placed on humanities and culture.
3. Fostering the socially valuable use of knowledge: beyond simply focusing on technology transfer to industry this also involves “cooperation with external actors for problem-solving in general” (Arocena et al., 2018, p. 169).

This approach to knowledge systems places the publicly funded tertiary education and research system as a central vehicle for guiding innovation processes towards SDGs. This will require new modes of engaged, problem-oriented research involving new hybrid roles for academic, public, private and community stakeholders collaborating in the production and application of new knowledge. This process is often referred to as the co-production of knowledge and is a central aspect of the literature on transdisciplinarity.

Box 1: examples of developmental universities approach:

Kruss et al. (2012). Analyses firm-university interactions in Uganda, Nigeria and South Africa in terms of sources of knowledge in firms' innovation activities, channels of interaction with universities and knowledge intensity of these interactions. These interactions are analysed in the context of the structural weaknesses of national innovation systems and adoption of 'horizontal' policies to develop 'threshold conditions' (i.e. capabilities across the NIS such as education and training system) and 'vertical' or 'targeted' policies to promote close links between universities and firms in new knowledge intensive sectors. Most firms in Nigeria and Uganda perceived Universities as irrelevant to their innovation strategies because they focused on 'big science' and instead relied on their internal capabilities and interactions with suppliers and customers for incremental innovation through a 'doing-using-interacting' mode of learning rather than a 'science technology and innovation' mode of firm learning (see Jensen et al 2007). In South Africa firms mainly relied also on interaction with suppliers and users but universities and networks with external knowledge partners (including public research institutes) have become strategically important as well, particularly for R&D performing firms that are larger and more technology intensive. "Interaction thus tends to occur in a limited number of sectors where the fields of university research capabilities match firms' technological specialisations and capabilities. The form of interaction... is typically formal, direct and relatively knowledge intensive, most commonly taking the form of a consultancy or contract to address immediate technology problems of firms," (p. 521). "The data trends thus suggest that the innovating and R&D performing firms that cooperate with universities represent the 'unstructured islands of innovation activity' " (p. 521). Important issues with firm-university interactions include: in the case of University support for innovation in agriculture in Uganda - "problems of sustainability, given the reliance on donor project based funding and the dearth of core government funding"; building the research system and technology transfer mechanisms in Nigeria - insufficient government and foreign donor funding, lack of S&T research resources and capabilities, university research running ahead of market demand so that new technologies remain "hidden or locked into the institution" (p. 526); fostering networks in targeted sectors in South Africa - "university based spin-off micro-enterprises offering bioinformatics consultancy services to foreign customers and clients." (p. 527), university-firm interactions focused on 'frontier science' in which "all of the firms involved are foreign" (p. 527), "The fledgling local productive sector is not able to take advantage of the latent opportunity inherent in existing research and knowledge generation capability, but it is unlikely that university-led commercial ventures can drive the process without a core local productive sector with key capabilities along the value chain." (p. 527). Further research needs: 1) move beyond narrow focus on firms in industrial sectors as services and agricultural sectors are also important and "demand for interaction with universities will arise from productive agents other than firms in the formal sector. Examples are subsistence farmers, small-scale producers in the informal sector, or community cooperatives." (p. 528); 2) analyse conditions, capabilities and interaction of firms in distinct sectors; 3) focus not only on S&T modes of innovation but also on "adaption and absorption of existing technologies new to the firm" and a 'doing-using-interacting' mode of learning ... which relies on internal processes of learning based on tacit knowledge." (p. 528) which

implies an important role for interactions with universities that are less knowledge intensive or direct; 4) analyse the role of national conditions and policies as well as international markets, regulatory systems, aid agencies and donors; 5) need comparative indicators of interaction to allow comparison with developing country thresholds.
For further examples and discussion see (Brundenius et al., 2011; de Mello et al., 2011; Kruss and Gastrow, 2017, 2015)

4. Transdisciplinary Research and Knowledge Systems for sustainability

There is a rapidly growing literature on sustainability science and transdisciplinary research for development. The focus is on the contribution of 'scholar-practitioner interactions' (Cash et al., 2003) or 'linkages between research-based knowledge and action' (Cornell et al., 2013; van Kerkhoff and Lebel, 2006) to sustainable development in terms of scientific knowledge being successfully mobilised to address environmental and social challenges by changing practices and policy (Lang et al., 2012; Pohl, 2008; Pohl et al., 2010). For example, through the sustainable management of natural resources and ecosystems, tackling climate change, supporting ecologically sustainable livelihoods, improving public health and environmental health.

A successful knowledge system enables relevant stakeholders (e.g. decision makers, managers, practitioners, community groups) to engage with the research process (at project level) at every stage including agenda setting, problem framing, knowledge production, communication and application of knowledge. For this, funders need to promote integration of multiple types of knowledge – e.g. scientific, local, practical, political (van Kerkhoff and Lebel, 2006) – and provide longer term funding – at least 10 years (Cash et al., 2003) to support continuous engagement. The function of 'boundary management' – working across the interface between knowledge and action – is particularly important accompanied by dual accountability between knowledge producers and users (Cash et al., 2003). Researchers need to take shared responsibility with practitioners for the impact of their research and adopt new roles of facilitation, knowledge brokering, negotiation and mediation of conflicting stakeholder interests, and recognised themselves as political actors within the knowledge system whose actions and research inevitably alters the distribution of power (Cornell et al., 2013; van Kerkhoff and Lebel, 2006).

Drawing on empirical examples of peri-urban development research, Marshall et al. (2018) argue for a reframing of transdisciplinary development research which moves beyond the narrative of the transfer of useable knowledge towards a deeper engagement with knowledge system actors – and their social and political context – with the aim of enhancing pro-poor transformative agency. Transdisciplinary research processes have the potential to connect alliances of actors across four arenas of knowledge systems: normative, cognitive, social, material. "Across these arenas, individual and collective agency can be exercised to shape normative agendas, assert alternative cognitive frames and visions, engage with and influence the social processes of governance, knowledge production, and practices, and alter the material conditions (e.g., ecological stocks and flows, infrastructure)." (Marshall et al., 2018, p. 10).

Echoing the developmental universities concept, Cornell et al (2013) argue for the need for what could be considered a 'transdisciplinary' research system (with new kinds of universities) which engages more deeply with societal actors and orients research and education towards sustainability problems and promoting the co-production of knowledge and sustainable practices and the cultivation of 'T-shaped' skills which enable experts to communicate across multiple disciplines and arenas of knowledge. The key elements of this 'open knowledge system' are 1) joint problem-framing and shared vision with academic and non-academic stakeholders; 2) Integration of knowledge 3) collaborative implementation 4) transformed link between research and education 5) long-term funding to allow continuity of engagement. Their argument is relevant to our conceptualisation of knowledge systems because it stretches the concept of knowledge systems beyond thinking about formal research institutions interacting with firms and funders towards thinking about how individuals, communities and third sector organisations are involved in the knowledge system particularly in relation to place-based research but also around global sustainability challenges. It also questions the purpose of science: knowledge as economic resource vs knowledge for the pursuit of social goals. "Our starting point is that the challenges of achieving sustainability require radical and deliberate changes in knowledge systems…. In particular, the interactions between scientists and other actors in diverse knowledge systems must be intensified, with scientific practices becoming more oriented toward the societal arenas in which sustainability problems are being tackled. We term this the 'opening up' of knowledge systems" (Cornell et al., 2013, p. 61).

The wider literature around sustainability science also discusses co-management of natural resources and social-ecological systems and the co-production of knowledge (Armitage et al., 2011; Olsson et al., 2010; van Kerkhoff and Lebel, 2015; Westley et al., 2013; Wyborn, 2015). This literature highlights the distributed nature of

transformative agency in the development of co-management arrangements. It also emphasises the importance of multi-level governance and institution building (such as multi-stakeholder management committees) to support evolving networks and alliance building between research, community and state actors which engage in collaborative knowledge production, inclusion of indigenous/local knowledge, shared learning, build adaptive capacity, shape and communicate vision for change and enlist and coordinate resources around shared strategies for transformation (Olsson et al., 2006; Westley et al., 2013).

5. Collaborative innovation and public-private partnerships

The themes of widening participation in innovation and knowledge systems to serve wider social goals have found expression in the application of innovation systems concepts to developing country agricultural sectors. Innovation systems approaches have been adapted as a way to guide intervention and investment in agricultural innovation and research in developing countries and some case studies and evaluations of agricultural innovation systems have been done (FARA, 2014; Hall et al., 2003; Spielman et al., 2009). The World Bank emphasised the need to improve on the 'national agricultural research system' (NARS) approach of the 1980s which focused on research supply, and the 'agricultural knowledge and information system' (AKIS) approach of the 1990s which focused additionally on more successfully linking research supply with farmers' demand. The world bank uses the innovation systems approach to highlight the need to support collaborative innovation processes through improving the interactions between multiple innovation system actors. Given the context of small-scale agriculture, innovation is given a more localised but conceptually broader definition to include not just new to market technologies or commercialisation of science but also applications of any kind of knowledge, organisational and institutional changes and alternative practices which are new to the individual or locale (World Bank, 2006, p. ix). This means that strengthening innovation systems and innovation capacity in developing countries is also a highly contextualised endeavour for which no single blueprint exists. It is therefore vital that investments and interventions are as responsive as possible to local agendas and conditions (Sumberg, 2005).

The value chain is also seen as an important element of the agri-innovation system (Meynard et al., 2017; World Bank, 2006, p. 21) and the innovation systems approach is now being adapted to enlarge the focus from the Agricultural Innovation Systems approach to encompass agri-food systems more broadly (Meynard et al., 2017). In one example, the connections between innovation systems and value chain concepts have been explored to present a 'co-innovation approach' to explaining the success and failure of government interventions to promote agri-food system innovation and guide policy makers drawing on two failed and one successful case in three African countries (Bitzer and Bijman, 2015). The argument is that innovation is best promoted as a 'collaborative' process involving multiple agri-food system actors bringing different resources and knowledge to achieve a shared economic or social goal. Next, in order to be successful, innovations need to be accompanied by 'complementary' changes in technical, organisational and institutional arrangements throughout the value chain. This requires intentional 'coordination' among actors and investments throughout the value chain, particularly in terms of enhancing vertical integration to make supply more responsive to demand (Bitzer and Bijman, 2015). The challenge for government is to facilitate collaboration, complementarity and coordination through investments and interventions and central importance is ascribed to private-sector involvement and the development of partnerships between public and private sector actors and between actors at different levels of the value chain, especially between farmers and agri-businesses further up the agri-food chain. This reflects a shift in emphasis towards knowledge exchange and supporting multiple actors to engage in innovation (especially farmers themselves). Along these lines, the World Bank describes a range of investment options across the agri-innovation system (World Bank, 2012) and provides lessons for designing policy interventions which facilitate more flexible and inclusive processes of innovation rather than focusing exclusively on research supply, extension and planning. Innovation networks, alliances and adaptive management (Fielke et al., 2018; Klerkx et al., 2010; Lamprinopoulou et al., 2014), knowledge brokers (Batterink et al., 2010; Klerkx and Leeuwis, 2009), multi-stakeholder processes (Kilelu et al., 2017) and social learning (Conley and Udry, 2010), are also discussed in the literature which reinforces the message that it is not enough to simply increase the supply of scientific knowledge and technology. Rather, innovation processes need to bring together a wider diversity of actors and knowledges - formal and informal – across public and private-sectors and multiple disciplines.

Public-private partnerships (PPP) have long been seen as an important policy option for achieving social and economic development by widening participation in processes and benefits of innovation (FCDO, 2003; EC, 2003; Horton et al., 2009; USAID, 2004). Brogaard and Peterson (2018) review the literature on PPPs in development policy, noting their application to infrastructure development (e.g. housing Koppenjan and Enserink, 2009), global health (Chataway et al., 2010), women's empowerment, poverty alleviation and climate change responses (e.g. Buso and Stenger, 2018). PPPs are seen as especially relevant to the agri-food and bioeconomy sectors as

a means of better linking knowledge supply with demand and for promoting more collaborative and coordinated innovation processes (Moreddu, 2016, p. 5; see also World Bank, 2012).

Hall (2006) applied an innovation system lens to PPPs to highlight the importance of strengthening linkages between, and building the capacity of, multiple agri-food innovation actors to mobilise local knowledge and actors. In addition to research-based PPPs (such as high-profile partnerships between big business and public research organisations for frontier science), PPPs involving networks of local agro-enterprises will likely be critical to rural development and poverty alleviation. Public research organisations thus need to be embedded in such networks which will require building social capital to form relationships of trust, cooperation and common purpose between organisations. Interventions should be aimed at improving the skills and capacity of policy and research actors to build social capital (e.g. training in participatory methods and problem solving, multi-disciplinary team building) and create contexts for farmers and local private agro-enterprises to interact with other innovation system actors (e.g. through farmer field schools, farmer and industry associations, multi-stakeholder working groups).

Spielman et al. (2010) analysed the experience of CGIAR research centres with PPPs, concluding that research objectives tackled by PPPs in agricultural research have been shifting from a narrow focus on technological innovation (e.g. increasing yields) to include organizational and systemic innovation as well (e.g. value chain development). They argue that PPPs have been relatively successful in increasing funding for agricultural research but less so in terms of promoting knowledge exchange in the form of tacit knowledge, technology donations or licensing, shared learning-by-doing or collaborations on innovations.

Moreddu (2016) discussed examples of PPPs for agricultural innovation in OECD countries and outlined the expected benefits from a PPP approach to innovation policy as:

1. Leverage public investment to reorient private investments in R&D towards public good, long time horizon and higher risk areas;
2. Improve private-sector contributions to government mission-oriented R&D;
3. Increase commercialisation of results from public research;
4. Upgrade knowledge infrastructures.

Moreddu (2016) also highlighted the enabling conditions that facilitate successful PPPs. Clear and reliable regulatory and legal frameworks, trusted institutions, stable macroeconomic conditions, well-functioning markets, affordable finance and good infrastructure are all important (Moreddu, 2016, p. 21). Specific interventions to support public R&D funding and provide financial incentives for PPPs to address social needs are suggested along with a call for capacity building for PPP participants. However, the absence of many of these 'enabling conditions' in low income countries begs the question of how PPPs operating under less-than-optimal conditions can be expected to achieve social and economic development goals without carrying higher risks of failure or unintended negative consequences.

Some of these risks have been highlighted in research on the development contribution of PPPs in other sectors such as solid waste management (Ahmed and Ali, 2004) and health (Kula and Fryatt, 2014; Roehrich et al., 2014). Ahmed and Ali suggest that PPP approaches common in developed countries (large conglomerates partnering with government agencies) may not be appropriate in developing countries and can create more corruption and inefficiency and worsen the livelihoods of the most vulnerable if poorly designed (Ahmed and Ali, 2004). They argue that an approach promoting vertical integration between small-scale operators and the public sector, supported by independent facilitating agencies stands a better chance of overcoming resistance from incumbent business interests and forming successful partnerships for service delivery.

A study of public-private interactions in the health sector in South Africa found that successful private-sector involvement in technological and organizational innovations will require upgrading the skills and capacities of public-sector actors in procurement, contracting and performance management (Kula and Fryatt, 2014). New forums for stakeholder participation will also need to be created in order to include networks of policy makers, academics, care providers and civil-society groups capable of reviewing and evaluating PPPs and collaborating on learning and innovation (Kula and Fryatt, 2014). Roehrich et al. (2014) reviewed the literature on PPPs in health service provision and innovation and identified several risks of PPPs including: higher capital costs, stifling of innovation, limited competition, high transaction costs, misallocation of risks. However, there is still a lack of evidence on the impacts of PPPs and the factors contributing to success of failure (Roehrich et al., 2014).

This literature implies that, as a tool for promoting innovation to achieve SDGs in agri-food, health, waste management and infrastructure sectors, PPPs can be effective parts of a broader strategy to strengthen knowledge systems and promote knowledge exchange and learning-by-doing. PPPs also carry the risk of unintended consequences – e.g. threat to informal livelihoods (Ma and Hipel, 2016) – and hidden costs alongside the risk of failure dependent on their institutional configuration and local context (Roehrich et al., 2014). To mitigate these risks, PPPs in low and middle-income countries should form part of an integrated

approach to strengthening legal, financial and governance institutions to ensure transparency, accountability and adequate resourcing. In relation to investments and interventions in knowledge systems, important prerequisites for successful PPPs include capacity building for participants, formal and informal knowledge exchange mechanisms and forums for diverse stakeholder involvement in design, monitoring and evaluation of interventions. In low and middle-income countries especially, efforts to support the agency and capacity of small-scale private sector and informal participants will also be necessary (Ahmed and Ali, 2004; see also Kirama and Mayo, 2016).

It is also important to recognise that the range of possibilities for technical, institutional and organisational change may be highly restricted when interactive processes of innovation occur under conditions of very uneven power relations within 'partnerships' or alliances and through the value chain. In this respect Vanloqueren and Baret (2009) provide a case study of how knowledge systems can shape innovation trajectories in agriculture. They conceptualise an agricultural research system as a sub-system of an innovation system and analyse the development of two technological paradigms in agricultural innovation: genetic engineering and agro-ecology. "A technological paradigm defines an idea of 'progress' by embodying prescriptions on the directions of technological change to pursue and those to neglect." (p. 972). "A technological trajectory is the "pattern of normal problem solving activity (i.e. of progress) on the ground of a technological paradigm" or, in other words, the improvement pattern of concrete solutions based on a paradigm." (p. 972). "Technological regimes are the (sets of) rules of the game that guide the direction of technological innovation and use (Possas et al., 1996)." (p. 973). The key influences on the direction of agricultural research systems they identify include: agricultural science policies, influence of lobbies and media, private sector research orientations, cultural and cognitive routines (values and world views of scientists), organisation within research systems (rules of the game such as 'publish or perish', level of specialisation or interdisciplinarity, technology transfer missions of universities measured in patents). They emphasise the need to understand the political economy of agricultural innovation and highlight the need to recognise the political nature of investments and interventions in agri-food systems and how these investments are influenced by wider socio-cultural, political-economic and scientific and technological contexts.

6. Sustainability Transitions

This literature is focused on the processes through which multiple socio-technical systems providing services such as energy, transport, food and water are transformed to generate more sustainable modes of production and consumption. Socio-technical systems are defined as networks of "actors (individuals, firms, and other organizations, collective actors) and institutions (societal and technical norms, regulations, standards of good practice), as well as material artefacts and knowledge (Geels, 2004; Markard, 2011; Weber, 2003)." (Markard et al., 2012, p. 956). Socio-technical transitions involve fundamental changes in each of these elements. This literature has been heavily biased towards studies of energy systems (plus transportation and water/sanitation) in European countries (Markard et al., 2012).

The underlying assumption is that transitions, while not amenable to control or attainable through centralised planning, are nevertheless governable in that they can be stimulated and guided with the right policies providing those policies are responsive and adaptable to the unpredictable evolution of socio-technical processes.

Within the transitions literature, the multi-level perspective (MLP) has proved to be a very influential approach to understanding the processes through which transitions occur (Geels, 2002). This approach has been developed into a highly sophisticated way of explaining long-term historical transitions in sectors as diverse as energy, transportation, waste management and agriculture (Geels and Schot, 2007). The MLP focuses on the interactions between three analytical levels of transitions: 1) socio-technical landscape; 2) socio-technical regime; 3) Niche-innovations.

The socio-technical regime expresses the idea that socio-technical systems evolve in mutual interaction and along a reinforcing trajectory of incremental change which can be considered relatively stable. Transition to an alternative socio-technical regime requires destabilisation of the incumbent regime. The alignment and scaling up of niche innovations coinciding with windows of opportunity created by landscape pressures leads to destabilisation and transition. Niches, in which new technologies or new forms of organisation or interaction with existing technologies emerge, can provide the seeds of transition as long as landscape pressures (long-term socio-economic and political changes or short-term shocks) lead to opportunities for niches to align, scale up, obtain resources and challenge the socio-technical regime.

In recent years, transitions thinking has had considerable impact on government sustainability policies, particularly in EU and OECD countries (EEA, 2016; OECD, 2015). These approaches aim to help governments initiate and guide local, regional or national sectoral (e.g. energy, transport, waste management, housing) transitions to sustainability. Transition management (Rotmans et al., 2001) is a high profile application of

transitions thinking to policy practice and has been tried with some success in the Netherlands (Loorbach, 2010) but also in some other developed countries (OECD, 2015). This approach specifies a cycle of four governance activities aimed at building consensus and co-ordinating resources, coalitions and actions throughout the unfolding transition pathways. The cycle of activities are: "(i) structure the problem in question and establish and organize the transition arena; (ii) develop a transition agenda, images of sustainability and derive the necessary transition paths; (iii) establish and carry out transition experiments and mobilize the resulting transition networks; (iv) monitor, evaluate and learn lessons from the transition experiments and, based on these, make adjustments in the vision, agenda and coalitions." (Loorbach and Rotmans, 2010, p. 238).

Transitions thinking is relatively new but already several critiques have identified weaknesses. These include, conceptual 'fuzziness' especially relating to the idea of socio-technical regimes' and how they are to be applied empirically (Berkhout et al., 2004; Sorrell, 2018). This is important because it creates difficulty in being able to detect and evaluate the extent of change (Sorrell, 2018). A further issue in using the framework in LMICs, is that it has little to say on capabilities or capacities for change.

Shove and Walker (2007) caution that "these approaches can all too easily obscure their own politics, smoothing over conflict and inequality; working with tacit assumptions of consensus and expecting far more than participatory processes can ever hope to deliver." (Shove and Walker, 2007, p. 768). Smith et al. (2005) also note the lack of attention to the role of agency and power inequalities in the construction of 'consensus' and offer an alternative explanation of transitions and a heuristic for guiding policy interventions. They propose a typology of transition contexts described by two dimensions of governance: "the *articulation* of selection pressures acting on the regime and the provision and coordination of resources for *adaptation*." (Smith et al., 2005, p. 1508). They "develop the concepts of 'endogenous renewal', 're-orientation of trajectories', 'emergent transformation' and 'purposive transition' as four ideal types of transformation that unfold under these different transition contexts." (Smith et al., 2005, p. 1508). The role of governance, then, is to facilitate the ongoing appraisal of a present transition context and design interventions to enhance the transition process or redirect it towards a more desirable type of transformation.

Despite these critiques, in relation to how we might conceptualise knowledge systems, transitions thinking helps to enlarge our perspective on what constitutes knowledge systems and how they might interact with broader processes of change. Knowledge systems may be envisaged as playing a role in the development and distribution (internal or external to regime) of knowledge and capabilities as well as supporting the co-ordination of those resources in response to or anticipation of landscape pressures. This suggests a function of knowledge systems in relation to governance which goes beyond providing knowledge to inform policy or drive economic activity through innovation. Knowledge systems can also be seen as integral to the formation of sustainability policy and planning as well as to the task of anticipating landscape shocks and pressures and informing preparation of responses. Addressing the Transformative Innovation Agenda (Schot and Steinmueller, 2016) in relation to rapidly urbanising contexts, Marshall and Dolley (in press) emphasise the importance of purposeful alliance building aimed at the transformation of knowledge systems. This shifts the focus away from niche management approaches to transitions governance towards more overtly political processes seeking to enhance the "capacity of alliances of actors to influence dominant framings of urban development, and to capture windows of opportunity." (Marshall and Dolley, in press).

There are three obvious ways knowledge systems can be placed in relation to the transitions literature:

1. As the infrastructure upon which successful governance of transitions depends, a kind of feedback mechanism of institutions, research activities and decision-making processes allowing governance processes to respond to transition processes as they unfold.
2. As an aspect of the 'socio-technical regime' in that "scientific knowledge, engineering practices, and process technologies are … intertwined with the expectations and skills of technology users, with institutional structures, and with broader infrastructures… [such that] it imposes a logic and direction for incremental socio-technical change along established pathways of development." (Markard et al., 2012, p. 957). Thus, a socio-technical transition involves an accompanying change in the knowledge system embedded within the socio-technical regime.
3. As a multiplicity of diverse, alternative knowledge systems (in some ways subverting the socio-technical regime) supporting: a) the emergence of niches in which new socio-technical configurations can be created, tested and developed; b) the formation and capacity of alliances of actors to influence dominant knowledge systems and potentially transform them.

7. Developing a practical knowledge system concept with sustainability goals in mind

If we start with a basic definition of knowledge systems as "a network of agents, practices and institutions that organise the production, transfer and use of knowledge", then this begs a further question. Assuming that such

networks form according to a relatively coherent collective purpose or alignment of purposes, this definition suggests multiple types of knowledge system that are relevant to achieving progress towards the SDGs.

A knowledge system is therefore a network of agents, practices and institutions that organise the production, transfer and use of knowledge in order to achieve some goal or set of goals. In crude terms we might summarise the literature as follows.

The innovation systems literature discussed above assumes a market-led, economic opportunity focused knowledge system with the goal of economic growth through industrialisation. Knowledge production is geared towards generating and mobilising knowledge that can be commercialised while also training a skilled workforce. Technological and process innovation are the focus.

Developing country critiques of innovation systems and the literature on public-private partnerships assume a broader goal for knowledge systems. That of social development with a greater role for (benign) government intervention. Knowledge production needs to embrace informal 'non-scientific' knowledge, be problem focused, public good oriented and empower citizens to participate in economic and political life. A wider definition of innovation is adopted to include institutional, practice and organisational innovation alongside adapting technological innovations to local contexts.

Transdisciplinary research and sustainability science assumes a knowledge system oriented towards more radical but locally embedded notions of sustainability. Knowledge production needs to engage citizens (and especially marginalised groups) in shaping research goals, producing knowledge and participating in capacity building and governance processes. Innovation includes - in addition to technological innovation - new methods of knowledge production and new institutional and governance arrangements and changes to the structure of public research funding.

Sustainability transitions implies a knowledge system oriented towards managing long-term change across multiple socio-technical systems to achieve sustainability goals. Knowledge production includes developing understandings of long-term trajectories of change, constructing visions of the future, charting pathways to achieving these visions and mobilising and coordinating action. Systems innovation is the focus and knowledge systems need to be shaped to support governance, undermine undesirable socio-technical regimes and facilitate niche innovations.

Linking these different perspectives together we could argue that a more integrated vision of a knowledge system is one which encompasses four 'wedges' of collective endeavour (see figure 1 below). In crude terms these four wedges can be described as:

1. Commercialization: (the focus of *innovation systems*) – a necessary goal to support a healthy economy but not the only one in relation to innovation more broadly defined.

2. Meeting people's needs (a wider definition of innovation found in the *innovation for development* literature) – the social justice, equity and local problem-solving elements of innovative activity which is often informal and driven by the necessity to develop coping strategies or by political pressure to solve urgent social needs. Often not coinciding neatly with the imperative to make money.

3. Empowering the poor (an increasing emphasis of *Transdisciplinary development/sustainability research*) – inclusive innovation means not simply sharing the benefits of innovation more widely but empowering the poor to participate and be supported in formal and informal processes of innovation and also to gain more power to influence the direction of innovation.

4. Making the 'system' sustainable and resilient (the focus of *Sustainability transitions*) – the large-scale and cross-scale feedbacks between social, technical and environmental change are important considerations for STI policy. Local changes have an impact on the 'system' (economic, ecological, socio-political etc.) as a whole and vice versa. These feedbacks need to be understood and taken into account when developing STI policy. This is the wedge of KS most clearly positioned as a part of the policy learning and governance process.

Each of these 'wedges' highlights different actors and implications for the production and use of knowledge as well as the enabling conditions which contribute to knowledge production, use and exchange (shown in concentric circles in figure 1.). A national policy, sectoral KS or specific intervention or project could each be mapped onto figure 1 as incorporating different combinations of knowledge using, producing and enabling elements and oriented towards one or more of the four major goals.

Figure 1. Different perspectives on Knowledge Systems.

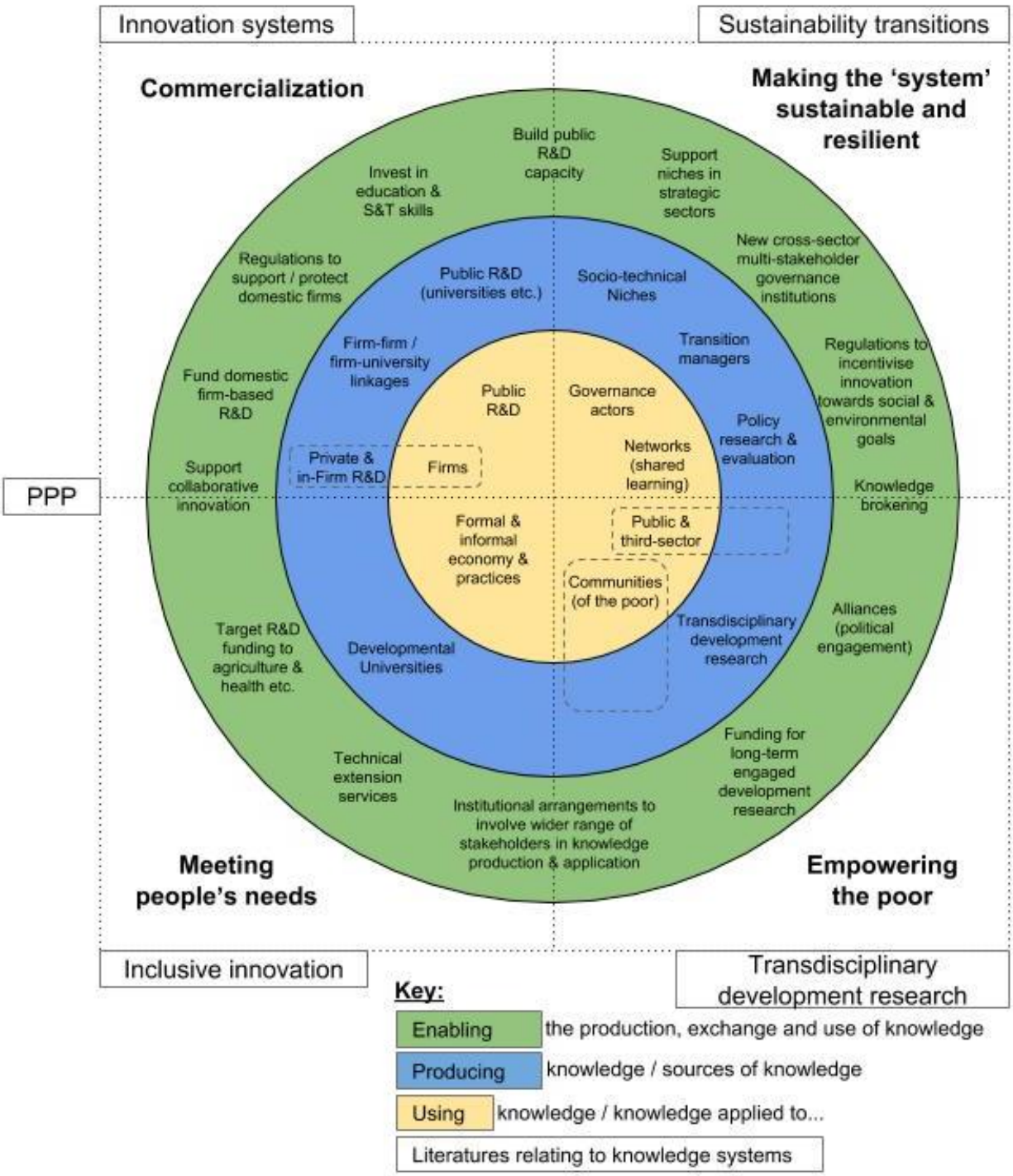


Figure 1. Different perspectives on Knowledge Systems

Incorporating the range of these different orientations in our concept of knowledge systems we suggest a matrix of typologies of knowledge systems mapped according to two axes:

1) the scale of economic returns to knowledge systems investment;
2) the responsiveness of knowledge systems to social and environmental agendas of society (e.g. SDGs).

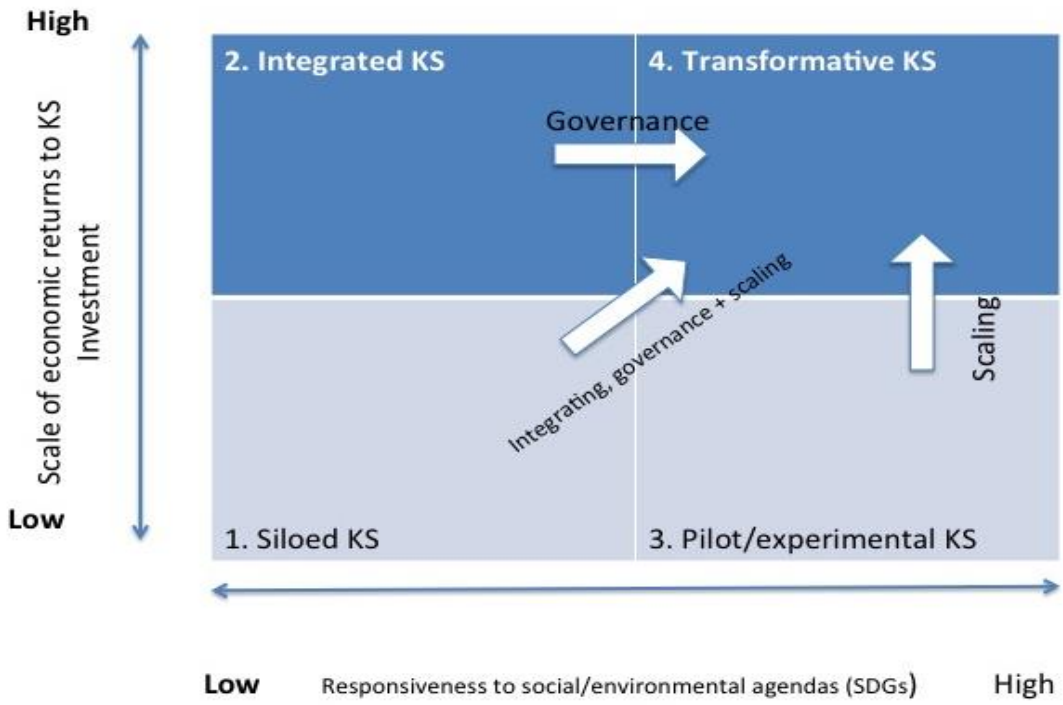
The following diagram (figure 2.) presents four quadrants of knowledge systems defined as follows:

- **Siloed knowledge system:** formal research systems disconnected from informal knowledge and from social and economic activity. Lack of frameworks and clear processes for knowledge use

leading to poor uptake of research, weak priority setting, and missing or weak governance mechanism. Skewed political economy toward powerful incumbents. Weak policy evaluation and learning thus relatively low economic returns.

- **Integrated knowledge system:** Productive links and partnerships between critical stakeholders in research and enterprise worlds. Informal knowledge sources acknowledged by policy with connections and support in place. Laissez-faire approach to innovation governance, largely driven by market forces.
- **Pilot or experimental knowledge system:** Extensive experiments on inclusive and sustainable production and consumption practices, business models and policy interventions. Often driven by civil society and peripheral players. Weak or missing value networks and evidence to leverage the scaling of successful pilots to catalyse socio-technical change.
- **Transformative knowledge system:** Alliances and governance mechanisms in place to direct innovation action towards social and sustainability issues and support growth driving innovation. Fluid knowledge flows between formal and informal knowledge sources and with policy. Strong culture of policy evaluation and learning and likelihood of high economic returns on investments.

Figure 2. Typology of knowledge systems



There are three major pathways of investment over and above research.

- Moving from Integrated KS (2) to transformative KS (4) requires investments that emphasize improved innovation governance.
- Moving from pilot/experimental KS (3) to transformative KS (4) requires investments that emphasize scaling and systems innovation (policy reform, consumer awareness etc.).
- Moving from siloed KS (1) to transformative KS (4) requires a combination of all of the above.

It is perfectly possible and indeed very likely for different knowledge systems to exist in one national context. Therefore, this matrix should not be viewed as characterising national systems but rather as a looser analytical tool to help us frame different initiatives and actors, to understand differences in knowledge systems capacity and the relationships of that to impact.

The scope of polices or schemes aimed at strengthening the knowledge system is potentially quite large and diverse and may include:

- **Interventions seeking to increase the production of knowledge.** Usually investments in research, research capability and research infrastructure. Investments in education and training.
- **Interventions that seek to disseminate knowledge.** Public advisory services (agriculture, business).
- **Interventions that seek to create connections between producers and users of knowledge.** May be schemes to link Universities and the private sector. Grant schemes that promote collaboration. Various form of knowledge related public private sector partnerships. Investments to create collaboration hubs, innovation platforms or domain specific networks.
- **Interventions that seek to strengthen the use of knowledge.** Business incubators, science parks, capacity building schemes targeting SME entrepreneurship and innovation. University graduate industry placement schemes.
- **Interventions that seek to support informal knowledge sources and build links to formal knowledge.** May include support to local experimentation and learning, for example farmer field schools. Interventions supporting local innovation and promoting local innovations, for example Polinova network (Honeybee network in India). Investments in the exploitation of ethno-botanical knowledge for medical purposes. Specialised research centres on traditional medicine, engineering, water management etc. Interventions that mobilise traditional healers in AIDS control and other public health schemes.
- **Interventions that seek to coordinate different elements of the knowledge system.** Investments in national innovation agencies.
- **Interventions that seek to make knowledge systems more responsive to social and environmental goals.**
  Creation of cross-sector multi-stakeholder governance institutions for natural resource management or to guide systems innovation in urban infrastructures, health services etc.

Bibliography

Ahmed, S.A., Ali, M., 2004. Partnerships for solid waste management in developing countries: linking theories to realities. Habitat International 28, 467–479. https://doi.org/10.1016/S0197-3975(03)00044-4

Alavi, M., Leidner, D.E., 2001. Review: Knowledge Management and Knowledge Management Systems: Conceptual Foundations and Research Issues. MIS Quarterly 25, 107–136. https://doi.org/10.2307/3250961

Armitage, D., Berkes, F., Dale, A., Kocho-Schellenberg, E., Patton, E., 2011. Co-management and the co-production of knowledge: Learning to adapt in Canada's Arctic. Global Environmental Change 21, 995–1004. https://doi.org/10.1016/j.gloenvcha.2011.04.006

Arocena, R., Göransson, B., Sutz, J., 2018. Developmental Universities in Inclusive Innovation Systems: Alternatives for Knowledge Democratization in the Global South. Palgrave Macmillan.

Batterink, M.H., Wubben, E.F.M., Klerkx, L., Omta, S.W.F. (Onno), 2010. Orchestrating innovation networks: The case of innovation brokers in the agri-food sector. Entrepreneurship & Regional Development 22, 47–76. https://doi.org/10.1080/08985620903220512

Bell, M., Albu, M., 1999. Knowledge Systems and Technological Dynamism in Industrial Clusters in Developing Countries. World Development 27, 1715–1734. https://doi.org/10.1016/S0305-750X(99)00073-X

Berkhout, F., Smith, A., Stirling, A., 2004. Socio-technological regimes and transition contexts., in: Elzen, B., Geels, F.W., Green, K. (Eds.), System Innovation and the Transition to Sustainability: Theory, Evidence and Policy. Edward Elgar, Cheltenham, pp. 48–75.

Bitzer, V., Bijman, J., 2015. From innovation to co-innovation? An exploration of African agrifood chains. British Food Journal 117, 2182–2199. https://doi.org/10.1108/BFJ-12-2014-0403

Brogaard, L., Petersen, O.H., 2018. Public-private partnerships (PPPs) in development policy: Exploring the concept and practice. Development Policy Review 36, O729–O747. https://doi.org/10.1111/dpr.12277

Brundenius, C., Göransson, B., Ågren, J., 2011. The role of academic institutions in the national system of innovation and the debate in Sweden, in: Göransson, B, Brundenius, C (Eds.), Universities in Transition. The Changing Role and Challenges for Academic Institutions. Springer, Ottawa, pp. 307–325.

Buso, M., Stenger, A., 2018. Public-private partnerships as a policy response to climate change. Energy Policy 119, 487–494. https://doi.org/10.1016/j.enpol.2018.04.063

Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jäger, J., Mitchell, R.B., 2003. Knowledge systems for sustainable development. Proceedings of the National Academy of Sciences 100, 8086–8091. https://doi.org/10.1073/pnas.1231332100

Chaminade, C., Vang, J., 2008. Globalisation of knowledge production and regional innovation policy: Supporting specialized hubs in the Bangalore software industry. Research Policy 37, 1684–1696. https://doi.org/10.1016/j.respol.2008.08.014

Chataway, J., Hanlin, R., Mugwagwa, J., Muraguri, L., 2010. Global health social technologies: Reflections on evolving theories and landscapes. Research Policy 39, 1277–1288. https://doi.org/10.1016/j.respol.2010.07.006

Chataway, J., Ochieng, C., Byrne, R., Daniels, C., Dobson, C., Hanlin, R., Hopkins, M., Tigabu, A., 2017. Case Studies of the Political Economy of Science Granting Councils in Sub-Saharan Africa (Full Report to the International Development Research Centre (IDRC), Science Policy Research Unit (SPRU), University of Sussex, United Kingdom, and African Centre for Technology Studies (ACTS), Kenya). Science Granting Councils Initiative (SGCI).

Chataway, J., Smith, J., Wield, D., 2007. Shaping scientific excellence in agricultural research. International Journal of Biotechnology 9.

Conley, T.G., Udry, C.R., 2010. Learning about a New Technology: Pineapple in Ghana. American Economic Review 100, 35–69. https://doi.org/10.1257/aer.100.1.35

Cornell, S., Berkhout, F., Tuinstra, W., Tàbara, J.D., Jäger, J., Chabay, I., de Wit, B., Langlais, R., Mills, D., Moll, P., Otto, I.M., Petersen, A., Pohl, C., van Kerkhoff, L., 2013. Opening up knowledge systems for better responses to global environmental change. Environmental Science & Policy 28, 60–70. https://doi.org/10.1016/j.envsci.2012.11.008

Cowan, R., David, P.A., Foray, D., 2000. The Explicit Economics of Knowledge Codification and Tacitness. Industrial and Corporate Change 9, 221–253.

de Mello, J.M.C., Maculan, A.-M., Renault, T.B., 2011. Brazilian universities and their contribution to innovation and development, in: Göransson, B., Brundenius, C. (Eds.), Universities in Transition. The Changing Role and Challenges for Academic Institutions. Springer, Ottawa, pp. 53–76.

DFID, 2003. Key Sheets: Public-Private Partnerships.

Dosi, G., Freeman, C., Nelson, R., Silverberg, G., Soete, L., 1988. Technical change and economic theory. Laboratory of Economics and Management (LEM), Sant'Anna School of Advanced Studies, Pisa, Italy.

EC, 2003. Guidelines for Successful Public-private Partnerships.

EEA, 2016. Sustainability Transitions: Now for the Long Term. European Environment Agency, Copenhagen.

FARA, 2014. FARA's 2014–2018 Strategic Plan: Enhancing African Innovation Capacity for Agricultural Transformation. Forum for Agricultural Research in Africa (FARA), Accra, Ghana.

Fielke, S.J., Botha, N., Reid, J., Gray, D., Blackett, P., Park, N., Williams, T., 2018. Lessons for co-innovation in agricultural innovation systems: a multiple case study analysis and a conceptual model. The Journal of Agricultural Education and Extension 24, 9–27. https://doi.org/10.1080/1389224X.2017.1394885

Fleck, J., 1993. Innofusion: Feedback in the innovation process, in: Systems Science. Springer, pp. 169–174.

Foray, D., Lundvall, B., 1998. The knowledge-based economy: from the economics of knowledge to the learning economy. The economic impact of knowledge 115–121.

Foster, C., Heeks, R., 2013. Conceptualising Inclusive Innovation: Modifying Systems of Innovation Frameworks to Understand Diffusion of New Technology to Low-Income Consumers. The European Journal of Development Research 25, 333–355. https://doi.org/10.1057/ejdr.2013.7

Freeman, C., 1995. The 'National System of Innovation' in historical perspective. Cambridge Journal of economics 19, 5–24.

Geels, F.W., 2004. From sectoral systems of innovation to socio-technical systems: insights about dynamics and change from sociology and institutional theory. Research Policy 33, 897–920. https://doi.org/10.1016/j.respol.2004.01.015

Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy 31, 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8

Geels, F.W., Schot, J., 2007. Typology of sociotechnical transition pathways. Research Policy 36, 399–417. https://doi.org/10.1016/j.respol.2007.01.003

Giuliani, E., Bell, M., 2005. The micro-determinants of meso-level learning and innovation: evidence from a Chilean wine cluster. Research Policy 34, 47–68. https://doi.org/10.1016/j.respol.2004.10.008

Gregersen, B., 2017. Role of Universities for Inclusive Development and Social Innovation: Experiences from Denmark, in: Universities, Inclusive Development and Social Innovation. Springer, pp. 369–385.

Hall, A., 2006. Public-private sector partnerships in an agricultural system of innovation: Concepts and challenges. International Journal of Technology Management & Sustainable Development 5, 3–20. https://doi.org/10.1386/ijtm.5.1.3/1

Hall, A., Rasheed Sulaiman, V., Clark, N., Yoganand, B., 2003. From measuring impact to learning institutional lessons: an innovation systems perspective on improving the management of international agricultural research. Agricultural Systems 78, 213–241. https://doi.org/10.1016/S0308-521X(03)00127-6

Horton, D., Prain, G., Thiele, G., 2009. Perspectives on partnership: A Literature Review (Working Paper 2009-3). International Potato Center, Lima, Peru.

Kilelu, C., Klerkx, L., Omore, A., Baltenweck, I., Leeuwis, C., Githinji, J., 2017. Value Chain Upgrading and the Inclusion of Smallholders in Markets: Reflections on Contributions of Multi-Stakeholder Processes in Dairy Development in Tanzania. The European Journal of Development Research 29, 1102–1121. https://doi.org/10.1057/s41287-016-0074-z

Kirama, A., Mayo, A.W., 2016. Challenges and prospects of private sector participation in solid waste management in Dar es Salaam City, Tanzania. Habitat International 53, 195–205. https://doi.org/10.1016/j.habitatint.2015.11.014

Klerkx, L., Aarts, N., Leeuwis, C., 2010. Adaptive management in agricultural innovation systems: The interactions between innovation networks and their environment. Agricultural Systems 103, 390–400. https://doi.org/10.1016/j.agsy.2010.03.012

Klerkx, L., Leeuwis, C., 2009. Establishment and embedding of innovation brokers at different innovation system levels: Insights from the Dutch agricultural sector. Technological Forecasting and Social Change 76, 849–860. https://doi.org/10.1016/j.techfore.2008.10.001

Koppenjan, J.F.M., Enserink, B., 2009. Public-Private Partnerships in Urban Infrastructures: Reconciling Private Sector Participation and Sustainability. Public Administration Review 69, 284–296. https://doi.org/10.1111/j.1540-6210.2008.01974.x

Kruss, G., Adeoti, J., Nabudere, D., 2012. Universities and Knowledge-based Development in sub-Saharan Africa: Comparing University–Firm Interaction in Nigeria, Uganda and South Africa. Journal of Development Studies 48, 516–530. https://doi.org/10.1080/00220388.2011.604410

Kruss, G., Gastrow, M., 2017. Universities and innovation in informal settings: Evidence from case studies in South Africa. Science and Public Policy 44, 26–36. https://doi.org/10.1093/scipol/scw009

Kruss, G., Gastrow, M., 2015. Linking universities and marginalised communities: South African case studies of innovation focused on livelihoods in informal settings. HSRC Press, Cape Town.

Kula, N., Fryatt, R.J., 2014. Public–private interactions on health in South Africa: opportunities for scaling up. Health Policy and Planning 29, 560–569. https://doi.org/10.1093/heapol/czt042

Lamprinopoulou, C., Renwick, A., Klerkx, L., Hermans, F., Roep, D., 2014. Application of an integrated systemic framework for analysing agricultural innovation systems and informing innovation policies: Comparing the Dutch and Scottish agrifood sectors. Agricultural Systems 129, 40–54. https://doi.org/10.1016/j.agsy.2014.05.001

Lang, D.J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., Thomas, C.J., 2012. Transdisciplinary research in sustainability science: practice, principles, and challenges. Sustainability Science 7, 25–43. https://doi.org/10.1007/s11625-011-0149-x

Leach, M., Rockström, J., Raskin, P., Scoones, I., Stirling, A.C., Smith, A., Thompson, J., Millstone, E., Ely, A., Arond, E., Folke, C., Olsson, P., 2012. Transforming Innovation for Sustainability. Ecology and Society 17. https://doi.org/10.5751/ES-04933-170211

Lee, K., Malerba, F., 2017. Catch-up cycles and changes in industrial leadership: Windows of opportunity and responses of firms and countries in the evolution of sectoral systems. Research Policy 46, 338–351. https://doi.org/10.1016/j.respol.2016.09.006

Loorbach, D., 2010. Transition Management for Sustainable Development: A Prescriptive, Complexity-Based Governance Framework. Governance 23, 161–183. https://doi.org/10.1111/j.1468-0491.2009.01471.x

Loorbach, D., Rotmans, J., 2010. The practice of transition management: Examples and lessons from four distinct cases. Futures 42, 237–246. https://doi.org/10.1016/j.futures.2009.11.009

Lundvall, B., 2007. National Innovation Systems—Analytical Concept and Development Tool. Industry & Innovation 14, 95–119. https://doi.org/10.1080/13662710601130863

Lundvall, B.-Å., 2010. National systems of innovation: Toward a theory of innovation and interactive learning. Anthem press.

Lundvall, B.-Å., Johnson, B., 1994. The learning economy. Journal of industry studies 1, 23–42.

Lundvall, B.-Å., Johnson, B., Andersen, E.S., Dalum, B., 2002. National systems of production, innovation and competence building. Research policy 31, 213–231.
Lundvall, B.-Å., Lorenz, E., 2012. Innovation and Competence Building in the Learning Economy: Implications for Innovation Policy, in: Asheim, B.T., Parrilli, M.D. (Eds.), Interactive Learning for Innovation. Palgrave Macmillan, London, pp. 33–71.
Ma, J., Hipel, K.W., 2016. Exploring social dimensions of municipal solid waste management around the globe – A systematic literature review. Waste Management 56, 3–12. https://doi.org/10.1016/j.wasman.2016.06.041
Malerba, F., 2002. Sectoral systems of innovation and production. Research Policy 31, 247–264.
Markard, J., 2011. Transformation of infrastructures: sector characteristics and implications for fundamental change. Journal of Infrastructure Systems (ASCE) 17, 107–117.
Markard, J., Raven, R., Truffer, B., 2012. Sustainability transitions: An emerging field of research and its prospects. Research Policy 41, 955–967. https://doi.org/10.1016/j.respol.2012.02.013
Marshall, F., Dolley, J., in press. Transformative innovation in peri-urban Asia. Research Policy.
Marshall, F., Dolley, J., Priya, R., 2018. Transdisciplinary research as transformative space making for sustainability: enhancing propoor transformative agency in periurban contexts. Ecology and Society 23, 8.
Meynard, J.-M., Jeuffroy, M.-H., Le Bail, M., Lefèvre, A., Magrini, M.-B., Michon, C., 2017. Designing coupled innovations for the sustainability transition of agrifood systems. Agricultural Systems 157, 330–339. https://doi.org/10.1016/j.agsy.2016.08.002
Moreddu, C., 2016. Public-Private Partnerships for Agricultural Innovation (OECD Food, Agriculture and Fisheries Papers No. 92). https://doi.org/10.1787/5jm55j9p9rmx-en

Nelson, R.R., 1993. National Innovation Systems: A Comparative Analysis. Oxford University Press.
OECD, 2015. System Innovation: Synthesis Report. Organisation for Economic Corporation and Development, Paris.
OECD, 2013. Innovation in Southeast Asia, OECD Reviews of Innovation Policy. OECD Publishing.
Olsson, P., Bodin, Ö., Folke, C., 2010. Building Transformative Capacity for Ecosystem Stewardship in Social–Ecological Systems, in: Armitage, D., Plummer, R. (Eds.), Adaptive Capacity and Environmental Governance. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 263–285.
Olsson, P., Gunderson, L.H., Carpenter, S.R., Ryan, P., Lebel, L., Folke, C., Holling, C.S., 2006. Shooting the Rapids: Navigating Transitions to Adaptive Governance of Social-Ecological Systems. Ecology and Society 11. https://doi.org/10.5751/ES-01595-110118
Padilla-Pérez, R., Gaudin, Y., 2014. Science, technology and innovation policies in small and developing economies: The case of Central America. Research Policy 43, 749–759. https://doi.org/10.1016/j.respol.2013.10.011
Pohl, C., 2008. From science to policy through transdisciplinary research. Environmental Science & Policy 11, 46–53. https://doi.org/10.1016/j.envsci.2007.06.001
Pohl, C., Rist, S., Zimmermann, A., Fry, P., Gurung, G.S., Schneider, F., Speranza, C.I., Kiteme, B., Boillat, S., Serrano, E., Hadorn, G.H., Wiesmann, U., 2010. Researchers' roles in knowledge co-production: experience from sustainability research in Kenya, Switzerland, Bolivia and Nepal. Science and Public Policy 37(4), 267–281.
Roehrich, J.K., Lewis, M.A., George, G., 2014. Are public–private partnerships a healthy option? A systematic literature review. Social Science & Medicine 113, 110–119. https://doi.org/10.1016/j.socscimed.2014.03.037
Rotmans, J., Kemp, R., van Asselt, M., 2001. More evolution than revolution: transition management in public policy. Foresight 3, 15–31. https://doi.org/10.1108/14636680110803003
Schot, J., Steinmueller, W.E., 2016. Framing Innovation Policy for Transformative Change: Innovation Policy 3.0 - Draft Version 2 (Draft Working Paper). Science Policy Research Unit (SPRU), University of Sussex, Brighton, UK.
Shove, E., Walker, G., 2007. Caution! Transitions Ahead: Politics, Practice, and Sustainable Transition Management. Environment and Planning A 39, 763–770. https://doi.org/10.1068/a39310
Smith, A., Stirling, A., Berkhout, F., 2005. The governance of sustainable socio-technical transitions. Research Policy 34, 1491–1510. https://doi.org/10.1016/j.respol.2005.07.005
Sorrell, S., 2018. Explaining sociotechnical transitions: A critical realist perspective. Research Policy 47, 1267–1282. https://doi.org/10.1016/j.respol.2018.04.008

Spielman, D.J., Ekboir, J., Davis, K., 2009. The art and science of innovation systems inquiry: Applications to Sub-Saharan African agriculture. Technology in Society 31, 399–405. https://doi.org/10.1016/j.techsoc.2009.10.004

Spielman, D.J., Hartwich, F., Grebmer, K., 2010. Public-private partnerships and developing-country agriculture: Evidence from the international agricultural research system. Public Administration and Development 30, 261–276. https://doi.org/10.1002/pad.574

Srinivas, S., Sutz, J., 2008. Developing countries and innovation: Searching for a new analytical approach. Technology in Society 30, 129–140. https://doi.org/10.1016/j.techsoc.2007.12.003

STEPS Centre, 2010. Innovation, Sustainability, Development: A New Manifesto. STEPS Centre, Brighton.

Stirling, A., 2009. Direction, Distribution and Diversity! Pluralising Progress in Innovation, Sustainability and Development (STEPS Working Paper 32). STEPS Centre, Brighton.

Sumberg, J., 2005. Systems of innovation theory and the changing architecture of agricultural research in Africa. Food Policy 30, 21–41. https://doi.org/10.1016/j.foodpol.2004.11.001

UN ECA, 2016. Africa's science, technology and innovation policies - national, regional and continental, in: Assessing Regional Integration in Africa VII: Innovation, Competitiveness and Regional Integration. United Nations, New York.

UNESCO, 2015. UNESCO science report, towards 2030: executive summary. United Nations Educational, Scientific and Cultural Organization, Paris.

USAID, 2004. Tools for Alliance Builders.

van Kerkhoff, L., Lebel, L., 2006. Linking Knowledge and Action for Sustainable Development. Annual Review of Environment and Resources 31, 445–477. https://doi.org/10.1146/annurev.energy.31.102405.170850

van Kerkhoff, L.E., Lebel, L., 2015. Coproductive capacities: rethinking science-governance relations in a diverse world. Ecology and Society 20. https://doi.org/10.5751/ES-07188-200114

Vanloqueren, G., Baret, P.V., 2009. How agricultural research systems shape a technological regime that develops genetic engineering but locks out agroecological innovations. Research Policy 38, 971–983. https://doi.org/10.1016/j.respol.2009.02.008

Viotti, E.B., 2002. National Learning Systems A new approach on technological change in late industrializing economies and evidences from the cases of Brazil and South Korea. Technological Forecasting 28.

Wangwe, S.M., Diyamett, B.D., Komba, A., 2004. Trends in R&D activities in Tanzania: Funding Sources, Institutional Arrangements and Relevance, Research on Knowledge Systems (RoKS). IDRC.

Weber, K.M., 2003. Transforming Large Socio-technical Systems towards Sustainability: On the Role of Users and Future Visions for the Uptake of City Logistics and Combined Heat and Power Generation. Innovation: The European Journal of Social Science Research 16, 155–175. https://doi.org/10.1080/13511610304522

Westley, F.R., Tjornbo, O., Schultz, L., Olsson, P., Folke, C., Crona, B., Bodin, Ö., 2013. A Theory of Transformative Agency in Linked Social-Ecological Systems. Ecology and Society 18. https://doi.org/10.5751/ES-05072-180327

Williams, L.D.A., Woodson, T.S., 2012. The Future of Innovation Studies in Less Economically Developed Countries. Minerva 50, 221–237. https://doi.org/10.1007/s11024-012-9200-z

World Bank, 2012. Agricultural Innovation Systems: An Investment Sourcebook, Agricultural and Rural Development. The World Bank.

World Bank, 2010. Innovation Policy: A Guide for Developing Countries. World Bank.

World Bank, 2006. Enhancing Agricultural Innovation: How to Go Beyond the Strengthening of Resesarch Systems, Agricultural and Rural Development. The World Bank.

Wyborn, C.A., 2015. Connecting knowledge with action through coproductive capacities: adaptive governance and connectivity conservation. Ecology and Society 20. https://doi.org/10.5751/ES-06510-200111

Annex 2a Terms of reference for regional advisory group

Background

FCDO's Research and Evidence Division, through the East Africa Research Hub, is funding an 18-month £541,000 research study to: 1) propose a practical and context specific knowledge system concept for Kenya, Tanzania and Rwanda which is informed by appropriate international evidence of what works in innovation and research system approaches; and 2) propose practical actions and recommendations for effective investments in science, technology and innovation (STI) by these countries and their partners.

Following a competitive tender process, a consortium led by the Natural Resources Institute (NRI) at the University of Greenwich was awarded the contract for this work, which began late in April 2018. The consortium also includes the Science Policy Research Unit (SPRU) at the University of Sussex, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and the African Centre for Technology Studies (ACTS). As a component of the programme a Regional Advisory Group along with three country Advisory Groups are to be established to provide advice and indeed challenge to the project implementing team. In turn, FCDO have established an overarching steering group to approve project outputs.

Functions of the Regional Advisory Group

The Regional Advisory Group will be convened to challenge project management to **ensure regional relevance along with technical rigour and quality of the study.** The group may also provide guidance in terms of options and avenues for disseminating study outputs. The group will serve in an advisory capacity without management responsibilities. Members are committed to:

- provide guidance and advice on the study design and implementation; and
- support the dissemination and uptake of the research findings. It will include key regional stakeholders and policy-makers promoting or supporting Science, Technology and Innovation in East Africa. Provide strategic advice, options and platforms through which study can influence regional STI policies.

Time Commitment

The Regional Advisory Group will be convened in July 2018 and it should exist until October 2019. Members will be provided with a period of two weeks to submit comments on each output. A maximum of four 1 hour meetings is envisaged over the evaluation's lifetime, with some reading/preparation time required in advance of each meeting.

Composition

Organization	Name	**Position**
FCDO East Africa	Dr. JP Ochieng	Team Leader
University of Rwanda	Prof. Nelson Ijumba	DVC-AAR and Chairperson
East Africa Science and Technology Commission (EASTECO)	Dr. Gertrude Ngabirano	Executive secretary
Science, Technology and Innovation Policy Research Organization - STIPRO	Dr. Bitrina Diyamett	Executive Director - STIPRO
Africa Union Science Technology and innovation Strategy	Dr. Mohamed Ahmed Hamdy	Senior Scientific officer
African Academy of Sciences	Dr. Isayvani Naicker	Director of partnerships and strategy
The National Research Foundation	Dr. Dorothy Ngila	Project Specialist

Annex 2b Terms of reference for national advisory committees: knowledge systems innovation

Background

FCDO's Research and Evidence Division, through the East Africa Research Hub, is funding an 18-month £541,000 research study to: 1) propose a practical and context specific knowledge system concept for Kenya, Tanzania and Rwanda which is informed by appropriate international evidence of what works in innovation and research system approaches; and 2) propose practical actions and recommendations for effective investments in science, technology and innovation (STI) by these countries and their partners.

Following a competitive tender process, a consortium led by the Natural Resources Institute (NRI) at the University of Greenwich was awarded the contract for this work, which began late in April 2018. The consortium also includes the Science Policy Research Unit (SPRU) at the University of Sussex, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and the African Centre for Technology Studies (ACTS). As a component of the programme a Regional Advisory Group along with three country Advisory Committees are to be established to provide advice and indeed challenge to the project implementing team. In turn, FCDO have established an overarching steering group to approve project outputs.

Functions of the National Advisory Committees

The three National Advisory Committees have been convened following the inception workshops held in June/July 2018 to provide advice and guidance at national level. The committees will provide the font of knowledge at national level and feedback on country-level engagements and ensure the relevance of the study. Specifically this will include:

- Providing advice on selection of country case studies that will be undertaken;
- Provide policy linkages in country;
- Identify research gaps during the project implementation period;
- Provide strategic support as required.

The committees will include a Government or National Research Council representative from each country; country Research Leads; and key representatives. The advisory committee will provide strategic advice, options and platforms through which study can influence national STI policies. The chair of the national committees will also be asked to serve on the Regional Advisory Group so providing a conduit to ensure linkage between national and regional advisory groupings.

Time Commitment

The National Advisory Committees will be convened in July 2018 and it should exist until October 2019. Members will be provided with a period of two weeks to submit comments on each output. A maximum of four 1-hour meetings is envisaged over the evaluation's lifetime, with some reading/preparation time required in advance of each meeting.

Composition

Tanzania Advisory Committee

Organization	Name	**Position**
Tanzania Commission For Science And Technology	Dr. Amos Muhunda Nungu	Executive Director
Tanzania Private Sector Foundation (TPSF)	Mr. Godfrey Simbeye	Executive Director

REPOA[9]	Dr Donald Mmari	Executive Director
Science, Technology and Innovation Policy Research Organization - STIPRO	Dr. Bitrina Diyamett	Executive Director
EcomResearch Group	Dr. Deograsias P. Mushi	Chairman Ecom Research Group
University of Dar es salaam	Dr. Kelefa Mwantimwa	KSI Focal point for Tanzania and Lecturer, University of Dar es salaam

Kenya Advisory Committee

Organization	Name	**Position**
National Commission for Science and Technology	Dr. Roy Mugira	Technical Director
FCDO East Africa Research Fund	Dr. JP Ochieng	Team Leader
Institute for Democracy Leadership and Empowerment in Africa	Dennis Kodhe	Executive Director
University of Nairobi	Prof. Shem Wandiga	Director ICCA
African Women in Agricultural Research and Development	Dorothy Mukhebi	Deputy Director

Rwanda Advisory Committee

Organization	Name	**Position**
University of Rwanda	Prof. Nelson Ijumba	DVC-AAR and Chairperson
Ministry of Education	Remy Twiringiyimana	Advisor to the Minister of Education
National Industrial Research and Development Agency-Rwanda	Kampeta Pichette Sayinzoga	Director General
Higher Education Council (HEC)	Dr. Marie Christine Gasingirwa	Applied sciences, quality development and enhancement analyst
Ministry of Education (MINEDUC)	Eng. Mike Hughes	STI adviser to the minister of Education
Private Sector Foundation	Mr. Geofrey Kamanzi	Director of Business Development and Trade

[9] Research on Policy Analysis

Annex 3 Draft academic paper: Mapping research systems in Kenya, Tanzania and Rwanda and their relation with the Sustainable Development Goals

Attached as separate document.