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Fostering Knowledge uptake in Emerging Innovation Systems

Enhancing Conditions for Innovation in Rwanda

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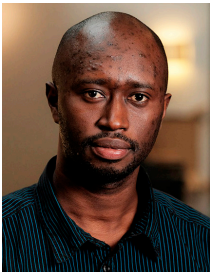
Knowledge, when used effectively, is a major input for development. However, the processes associated with knowledge production, knowledge transfer, and knowledge use are complex and not easy to facilitate in certain parts of the world. This is mainly due to a lack of or limited interactions between knowledge producers and knowledge users. Parfait Yongabo, in this thesis, explores how efforts to foster knowledge uptake are organized to support innovation and development in the context of emerging innovation systems. He analyses how the concept of a 'National Innovation System' has been adopted in this context and how the adoption of this concept aligns with other policies and development initiatives that are directed towards achieving efficient use of knowledge for development.



He answers the question of "If and how do NIS and associated policy initiatives enable interactive learning for innovation and development in Rwanda?" From empirical evidence, he concludes that progress has been made in adopting the 'NIS' concept in Rwanda and that a NIS can serve as a good framework for the use of knowledge for innovation and development. However, this can only take place if institutional relationships are strengthened. This can be achieved through coherent and responsive policies, smooth stakeholders' interactions, efficient resource mobilization and allocation, and infrastructure development.

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Parfait YONGABO

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DOCTORAL DISSERTATION

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Abstract

Knowledge, when used effectively, is a major input for development. However, the processes associated with knowledge production, knowledge transfer, and knowledge use are complex and not easy to facilitate in certain parts of the world. This is mainly due to a lack of or limited interactions between knowledge producers and knowledge users. This thesis aims to explore how efforts to foster knowledge uptake are organized to support innovation and development in emerging innovation systems. It does so by analysing how building National Innovation Systems and associated policy initiatives can enable interactive learning for innovation and development in Rwanda. This thesis portrays the policy initiatives and institutional frameworks that have been introduced (so far) to foster knowledge production and its use which is aimed at addressing the needs and challenges that Rwandan society currently faces. I have chosen the Rwandan agricultural sector (as a comprehensive economic sector) to explore these issues. Empirical findings from interviews and secondary data show that Rwanda has made progress in establishing Science, Technology and Innovation institutions and attendant policies. However, the research capacity of these institutions remains comparatively low and collaboration among stakeholders is scant. Notwithstanding this, there is a great deal of political will to promote innovation and make it a key driver for national socio-economic development. This political will favours the construction of a National Innovation System, that is promising and forward-looking to building relationships among stakeholders that can be used to promote knowledge production and use. Nevertheless, the industrial sector in Rwanda is still at an embryonic stage and R&D investment from both the business sector and the government remains negligible. All of these efforts need to be sustained and improvements in policies and policy instruments should be made so as to (i) strengthen relations between actors and (ii) mobilize resources for the production and use of knowledge.

Key words
Knowledge, innovation, research, institution, policy, innovation system

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Dedicated to my wife, Claudette,
my brother, Principe and
my mother, Marcianne!

"Always try to associate with people from whom you can learn something. All the knowledge that you want is in the world, and all you have to do is go and seek it." ***- Marcus Garvey***

"Science investigates; religion interprets. Science gives man knowledge, which is power; religion gives man wisdom, which is control. Science deals mainly with facts; religion deals mainly with values. The two are not rivals."
-Martin Luther King, Jr

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Whilst learning is a process, knowledge is a cumulation of values, attributes, and intellectual capabilities that are acquired over time through different forms of interactions. My PhD journey has been a learning opportunity (in all senses of the word) for me, and I believe that I acquired the knowledge that I now possess by adopting different perspectives. This journey could not have been possible without the support of my supervisors, family, colleagues, and friends. With these words, I would like to express my warm and profound gratitude to them.

I am aware that my journey was particularly long, but this provided me with the opportunity to meet a variety of people on different occasions. I thus recognize everybody who supported me in many ways, either directly and indirectly. I wish that I could mention everyone by name in this short acknowledgement.

Even though the list of names that I can mention here is somewhat long, I would like to start with my supervisory committee; a group of scholars who have guided me through the whole process. Their academic and scientific support was of capital importance. Without them, it would have been more challenging for me than it was to navigate through all the dynamics involved in the PhD process. Specifically, Mats Benner, I would like to thank you for your enthusiasm, leadership, and professionalism that characterized all of our interactions during my PhD studies. I learned a lot from you, not only the good theories that you were able to simplify for me whilst I was struggling to understand them, but I also thank you for your sense of humour, which I hope will become the main ingredient in my future career. Yes, I know that many may consider engaging in PhD studies as involving formal and professional relationships, but it is made much more enjoyable when it is made part of our routine, daily life activities. Thank you very much, Bo Göransson for allowing me to have many moments of enjoyment during my PhD student life. It was nice to have you as my supervisor, but your care and your welcoming spirit made my life more enjoyable. I felt that I could speak freely with you at any

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Jah Bless!!!

Table of Contents

List of figures

List of tables

List of papers

Paper I:
Yongabo Parfait. (2021). Research and innovation uptake landscape in Rwanda: Analysis of the STI framework. In: Daniels C., Dosso M., Amadi-Echendu J. (eds) *Entrepreneurship, Technology Commercialisation, and Innovation Policy in Africa*. Springer, Cham. https://doi.org/10.1007/978-3-030-58240-1_10 .

Paper II:
Yongabo Parfait & Bo Göransson (2020): Constructing the national innovation system in Rwanda: Efforts and challenges, *Innovation and Development*, DOI: 10.1080/2157930X.2020.1846886 .

Paper III:
Yongabo Parfait & Devrim Göktepe-Hultén. (2021). Emergence of an Agriculture Innovation System in Rwanda: Stakeholders and policies as points of departure. *Industry and Higher Education*, DOI: 10.1177/0950422221998610.

Paper IV:
Yongabo Parfait. (2021). Technologies and innovation trajectories in the Rwandan Agricultural sector: Are value chains an option? *African Journal of Science, Technology, Innovation and Development,* DOI: 10.1080/20421338.2021.1889769.

1. Introduction

Knowledge, when used effectively, is a major input for development. However, the processes associated with knowledge production, knowledge transfer, and knowledge use for development are considered to be challenging. Notwithstanding this, they remain at the centre of discussions in academic and policy communities (Mytelka and Smith 2002; Jacob 2006; Etzkowitz and Dzisah 2008; Lundvall 2010; Chaminade and Lundvall 2019). Identification of missing link between (A) knowledge production and (B) knowledge use is among the key challenges to facilitating the process of knowledge use (Göransson et al. 2016; Juma 2016). The process is complex and multidimensional. Thus, it requires implementing systemic facilitation mechanisms that can capture the dynamics involved in the process whilst taking the peculiarities of different contexts into account. This, in turn, requires policies and institutions that allow for interactions and learning among development agents so that they can bridge the gap between knowledge production and knowledge use (Lundvall 1998; Juma and Yee-Cheong 2005; Muchie and Baskaran 2017).

The demand for efficient policies and institutions that can be used to enable the systemic mechanisms to facilitate the production and use of knowledge has prompted an increased interest in developing countries regarding policy learning from advanced economies, such as Europe and North America. These advanced economies have made discernible progress in bridging the gap between the production of knowledge and the use of knowledge. These economies have put into place concepts, frameworks, and policy instruments that position knowledge in their development strategies. A 'National Innovation System' (NIS) is one profiled concept that these developed countries have adopted. We note that several developing countries have also expressed interest in the concept. (Lundvall 2012, Scerri 2016).

An NIS is generally defined as a set of institutions that interact in the production, diffusion, and use of economically useful knowledge, providing the framework in which governments form and implement policies to influence the innovation process. A national system encompasses organizations and

relationships, either located within or rooted inside the border of a nation state. The set of routines, behaviours, laws, regulations, and the rules of the economic 'game' constitute the institutions that fall within the ambit of the NIS concept. Note that these institutions are fundamental to interactive learning between industries and universities (Metcalfe and Ramlogan 2008; Edquist and Hommen 2008; Lundvall 2010). Although 'NIS' has become a popular concept, it has been criticized for not providing sufficient detail on how specific organizations within an innovation system might collaborate with each other and, in turn, produce innovation. Consequently, we need alternative, complementary tools to explore specific issues related to actors' interactions. The Triple Helix Model is one such potential tool that can complement the NIS concept as we explore these issues (Jacob 2006; Leydesdorff and Zawdie 2010).

The Triple Helix Model (TH) is used to analyse the relationship between universities, the private sector (most often industries), and the government. It explores the dynamics that are present in organized knowledge production, wealth generation, and organizational control (Lawton Smith and Leydesdorff 2014). With these functions, the TH is a valuable tool that can be used to organize the empirical analysis of the dynamics underlying interactions between and within organizations that are involved in a National Innovation System. Moreover, the functions of wealth generation, organized knowledge production, and organizational control capture the cultural and behavioural patterns of actors who are engaged in the interactions involving the production and use of knowledge, which, undoubtedly, form part of a national innovation systems (Leydesdorff and Zawdie 2010).

In addition to the relationships that can be empirically analysed by using the TH, mutual learning among actors is key for innovation systems. Consequently, they should be adequately understood. In this regard, the concept of Value Chain (VC) offers us the opportunity to explore how (i) mutual learning and (ii) competency-building are organized and performed at different stages of the value chain (Pietrobelli and Rabellotti 2011). This, in turn, emphasizes the understanding of how the integration of technology and innovation are organized in value chains. Value chains comprise a set of activities and networks of actors engaged in the production process—from a product's design to its consumption (Gereffi 1999). These networks of actors form part of innovation systems at different levels. The close link (and even their co-evolution) between innovation systems and value chains can enhance knowledge transfer and innovation. However, this requires thorough scrutiny, depending on the peculiarities of different contexts. This is particularly the

case in the context of developing countries where value chains appear to be short and innovation systems are not mature (Lema et al. 2018; Ernst and Kim 2002). Consequently, understanding how value chain structures and operations allow for integrating technology and innovation through mutual learning between actors will enable us to explore how knowledge transfer is facilitated in an emerging innovation system.

Using the same line of thinking, this thesis uses the NIS concept as the overall analytical framework for exploring the efforts and mechanisms which are used to foster knowledge uptake in the context of a developing country, namely, Rwanda. My study also uses TH and VC to explore the inner workings of the NIS in the context of Rwanda. Rwanda is an African country that has registered high levels of economic growth over the past few decades and aspires to achieve knowledge-based development. However, it is still facing challenges regarding how it can foster the production, transfer, and use of knowledge to achieve its developmental aspirations (UNCTAD 2017; NISR 2019a; MINECOFIN 2020).

This thesis does not aim to confirm or disqualify the validity of the NIS concept in the Rwandan context. Rather, it focuses on how the concept has been integrated into the Rwandan context and how it can serve as a point of departure to foster the use of knowledge for socio-economic development in Rwanda. The thesis sets its boundaries around issues of (i) policy, (ii) institutional capacity building, (iii) interactions and learning among actors, and (iv) how such interactions and learning can be facilitated for the purpose of enhancing the use of produced knowledge for development. The thesis does not focus on technology absorption *per se*, nor on the NIS performance itself.

1.1. Setting the stage: Positioning the thesis in the field

Although 'innovation systems' has become a popular concept relevant to understanding and organizing the use of knowledge for economic growth, this popularity did not happen overnight. Several models have been tried in the past and have subsequently evolved from linear models to complex and interactive models (Lundvall 1998; Etzkowitz and Leydesdorff 2000; Godin 2017). Research on the evolution of these models has focused on the innovation process and how innovation contributes to development. Thus, innovation studies have evolved as a field of study while focusing on theoretical and

empirical studies. Theoretical works have addressed people's understanding of the innovation process, which encompasses different stages, from discovery to wealth generation. On the other hand, empirical studies have examined particular tools and frameworks to explore innovation[1] in the development process. This has stimulated the evolution of different models which can be used to explore the complexities of the innovation process; including the chain-linked model, innovation clusters, value chains, competence blocs, and innovation systems, to mention a few. All of these were developed to examine the complex interactions in the innovation process (Kline and Rosenberg 1986, Manley 2002).

Despite the popularity and high interest in the concept of 'innovation systems', it needs to be adapted for different contexts. In emerging innovation systems, for example, in developing countries, a deep understanding of the interactive mechanisms for innovation is called for to ensure that the nature of institutions and relationships between actors enable or accommodate innovation activities. This can be achieved by focusing on specific issues pertaining to how actors interrelate with each other and examining the major driving factors behind these relationships (Lundvall et al. 2009). To perform such an analysis within the framework of innovation systems requires that we examine how specific actors interact with each other and how the 'rules of the game' are established. The Triple Helix offers the researcher an interpretive space where these specific issues can be captured by focusing on major actors, such as universities, companies, and government, and by examining how these actors are involved in the innovation process. The TH also helps us to analyse how innovation policies are formed and implemented (Jacob 2006; Leydesdorff and Zawdie 2010). It has been argued that various modes of policy formation constitute one of the key pre-conditions for maturing and stabilizing an IS (Muchie, Lundvall, and Gammeltoft 2003; Djeflat 2015).

Thus, the adoption of the concept of 'NIS' is a learning process that requires a good understanding of the peculiarities of the context in which innovation takes place (Altenburg 2009). The current literature on innovation systems does not offer us a blueprint for how to build an innovation system. This has led to the debate concerning whether the Global South should follow the template from the Global North to build their innovation systems as a means to facilitate the use of knowledge for development or whether the countries in

[1] This thesis refers to the Oslo Manual (OECD 2018) for a definition of 'innovation' and other associated concepts, including 'innovation activities', 'innovation process', and 'innovation categories' (see Paper II).

the Global South should follow different routes towards building their NIS. This thesis engages with this debate by unravelling how 'NIS' has been introduced and implemented in Rwanda as a tool that is intended to foster the use of knowledge for development.

An awareness of and discussions about innovation systems are on the rise in Rwanda (NCST 2020a). However, the main issue is to establish how such an interactive model might be implemented and how it might fit in with the political and institutional structures in Rwanda. This goal thus demands that we closely examine specific issues, including policies and institutional relationships, and the use of empirical evidence to analyse challenges that a proposed NIS faces in the Rwandan context.

1.2. Research aim and research questions

This thesis takes its point of departure in the limited understanding and the low number of empirical studies on NIS in developing countries, and the lack of research on which tools might be deployed to support the construction of NIS. To this aim, I focus on an empirical analysis of specific issues, including the relationships between organizations, policy formation, and policy implementation as part of building the NIS. I use Rwanda as an empirical case study in my exploration of these issues at two levels: the macro level (national) and meso level (agricultural sector).

Specifically*, this thesis aims to explore how efforts to foster knowledge uptake are organized in the context of emerging innovation systems that are directed towards the enhancement of innovation and development. It does so by analysing how the concept of a 'National Innovation System' has been adopted in this context and how the adoption of this concept aligns with other policies and development initiatives that are directed towards achieving efficient use of knowledge for development.*

To achieve this aim, this thesis responds to the following primary research question: *If and how do NIS and associated policy initiatives enable interactive learning for innovation and development in Rwanda?*

This research question gives rise to the following subordinate research questions:

- *How has the concept of 'NIS' been adopted and implemented in Rwanda?*

- *What are the pre-conditions for building an Innovation System within the agricultural sector in Rwanda in terms of policymaking, the stakeholders' engagement, and integrating technology and innovation?*

These research questions are addressed in each of the four papers that are included in this thesis. Table 1 shows how the individual papers answer these questions.

Table 1: The connection between the research questions and the papers included in this thesis

Research Question	Title of the paper	Scope of the paper
How has the concept of 'NIS' been adopted and implemented in Rwanda?	Research and innovation uptake landscape in Rwanda: Analysis of the STI framework	This paper explores the drivers for and constraints on research and innovation uptake in Rwanda. It profiles STI policy and institutional frameworks as well as capacity-building efforts.
	Constructing the National Innovation System in Rwanda: Efforts and challenges.	This paper examines how the concept of 'NIS' has been received by the STI community and how well it has been integrated into the capacity-building process for sustainable innovation capabilities. Moreover, it identifies the major efforts and challenges that building the Rwandan NIS faces.
What are the pre-conditions for building an Innovation System within the agricultural sector in Rwanda in terms of policymaking, the stakeholders' engagement, and integrating technology and innovation?	Emergence of an Agriculture Innovation System in Rwanda: Stakeholders and policies as points of departure	This paper identifies the key stakeholders and analyses how policy instruments contribute to the emergence of the agricultural innovation system in Rwanda whilst assessing the policymaking approaches.
	Technologies and innovation trajectories in the Rwandan Agriculture sector: Are value chains an option?	This paper analyses value chain activities and explores how value chain actors interact with each other to produce, transfer and use knowledge in the Rwandan agricultural sector.

1.3. Main contributions

By addressing the above questions, this thesis provides insight into the process of developing an NIS in Rwanda. It presents several policymaking options for innovation policies that would support building endogenous capacity for innovation, promoting development initiatives in Rwanda. I also discuss how efforts have been coordinated among actors to enable and perform innovation activities in Rwanda. I do so by showing how actors perform their roles and functions to create synergies in the process of knowledge production, transfer,

and use. I thus shed light on how knowledge can be positioned in the development process in emerging innovation systems, as found in Rwanda. Empirically, the thesis provides insight into (i) the question of how the NIS concept has been adopted in the context of Rwanda (a developing country) and (ii) how policies might be designed to promote innovation and achieve knowledge-based development.

Ultimately, my research contributes to the ongoing debate about the relevant factors and conditions for innovation in emerging innovation systems in developing countries. I contend that building innovation systems in the context of developing countries should take into account the peculiarities of these countries and that innovation policies and supporting public policies are key preconditions for the successful alignment of innovation activities to development initiatives. Stakeholders and their interactions with each other are foundational to the NIS, and the quality of institutions is crucial to establishing and maintaining harmonious relationships between actors and beneficial collaborations among actors. Such foundations allow for synergies and complementarities to emerge that lead to the efficient use of knowledge for development. Emerging innovation systems can operate at different levels, but the case of Rwanda can be inspirational to many other developing countries that aim to build sustainable innovation systems to foster the use of knowledge for development, particularly small African countries.

2. Theoretical Foundations

The theoretical conceptualization of this thesis builds on the assumption that knowledge is a significant contributor to socio-economic development. However, for knowledge to contribute to socio-economic development, knowledge production and knowledge use need to be organized so that knowledge can address community problems and improve the conditions for economic growth and living standards (for example, by improving living conditions). This can be achieved through interactive and systemic processes of knowledge production, transfer, and use for innovation. These processes require a set of interconnected activities that are built on interactive learning, synergies, and efficiency.

These activities need to be organized and performed in a manner that takes into account the available resources, what problems are to be addressed, and the expected impacts. In order to facilitate this, operational frameworks are needed that set structures and mechanisms that allow for a flow of knowledge (or knowledge co-production) between development agents. Different concepts and theories have been developed in the literature, each with different narratives, to explain how the facilitation of knowledge production, transfer, and use can be organized. Many concepts are descriptive and normative. However, they can inspire the close analysis of particular situations and the development of operational tools for the facilitation of knowledge use.

The following sub-sections discuss several key concepts that are used as a reference to structure my research and address my research questions. The main concepts used include ‘Innovation System’ (National Innovation System, primarily), the ‘Triple Helix Model’, and the ‘Value Chain Model’ (commodities value chain). The discussion of key concepts in this section is complemented by the comprehensive literature review in the individual papers that comprise this thesis.

2.1. Innovation systems: National-sectoral

The 'Innovation Systems' (IS) concept focuses on the complex and interactive process of innovation. It places innovation at different levels (micro-meso-macro) as the driving force behind economic growth. It considers knowledge as the main asset and learning as the main process (Freeman 1991; Metcalfe and Ramlogan 2008; Baskaran and Muchie 2017). Innovation systems research has primarily focused on examining institutional settings and interactive learning that takes place between knowledge producers and knowledge users. It has become a popular concept and has been profiled as a comprehensive framework in both the academic and policymaking communities. However, it has subject to criticism for as suffering from a lack of specificity with regards to matters of policy, the facilitation of interactions, and claimed deficiencies in its explanatory power (Jacobsson and Bergek 2006; Niosi et al. 1993; Borrás and Laatsit 2019; Jacob 2006; Mytelka and Smith 2002). Moreover, the use of the term *system* cannot be clearly delineated in the context of the innovation process (Smith 1994; Godin 2009). Despite all of these challenges, IS remains a powerful concept which can be used to understand how knowledge contributes to economic growth. I argue that its shortcomings can be addressed by applying it in conjunction with other complementary concepts.

Different scholars have provided several definitions of 'innovation systems' (See: Lundvall 2010; Freeman 1991; Nelson 1993; Edquist and Lundvall 1993; Niosi et al. 1993; Patel and Pavitt 1994; Metcalfe 1995). What is shared across these definitions are the relationships between agents for the production, transfer, and use of knowledge for economic growth. Lundvall (2010) provides a more elaborate definition of NIS and suggests the following six key elements of an NIS: (i) the internal organization of firms, (ii) inter-firm organization, (iii) the role of the public sector, (iv) institutional set-up of the financial sector, (v) R&D intensity, and (vi) R&D organization. Lundvall provides narrow and broad definitions of NSI based on these elements and how relationships are organized between them. In this thesis, Lundvall's definition[2] is applied in

2 "A system of innovation is constituted by elements and relationships which interact in the production, diffusion and use of new and economically useful knowledge and that a national system encompasses elements and relationships, either located within or rooted inside the border of nation state.

The narrow definition would include organizations and institutions involved in searching and exploring—such as R&D departments, technological institutes and universities. The broader definition includes all parts and aspects of the economic structures and the institutional set up affecting learning as well as searching and exploring the production system, the marketing

different ways to examine how NIS foster the use of knowledge for development.

The pioneering work by Freeman (1987), Lundvall (1992), and Nelson (1993) focuses on the factors behind successfully functioning innovation systems at the national level. The NIS thus analyses macro indicators regarding interactions between actors, organizations, institutions, and learning processes. In addition, the NIS examines the facilitation mechanisms of interactions, whilst considering the interactions between organizations such as universities and firms as a key element for innovation and its use for economic growth (Lundvall 2010; Chaminade et al. 2018). Organizations may generally be categorized as either knowledge producers or knowledge users. Institutions play a crucial role in innovation systems because they regulate behaviour and forms of interaction. In this context, institutions are considered to instantiate a set of routines, norms, regulatory tools, and policies (Edquist and Hommen 2008; Freeman 1995; Marius et al. 2005).

Although 'National Innovation System' is profiled as the most popular concept, the concept of an 'innovation system' has been adapted to other levels of analysis, including the technological, regional, and sectoral levels. With these levels, the concept of 'innovation systems' can be re-framed as either a *Technological* Innovation System, a *Regional* Innovation System, or a *Sectoral* Innovation System (Cooke 2002; Malerba 2007; Lundvall 2010; Baskaran and Muchie 2017).

Sectoral Innovation System is an example of a meso level innovation system that is usually built on three core components within a specific sector: (i) actors and networks, (ii) technology and knowledge, and (iii) institutions. These interconnected components can vary from one sector to another, depending on the operational environment. Actors and their networks are seen as crucial since the dynamics within and across networks and the types of actors directly influence the forms of interactions and learning that are likely to occur (Malerba 2007; Baskaran and Muchie 2017). Interest, opportunities, operations, and the market are other factors that can shape networks. These factors may also define the type of innovation or potential innovation that can succeed within the sector (Bullinger et al. 2004). Sectoral Innovation Systems can be analysed within a region or a country. Thus, a sectoral innovation

system and the system of finance present themselves as subsystems in which learning takes place (Lundvall 2010)."

system can be used to analyse the potential of a country with regard to the adoption of a more overarching national innovation system.

The type of actors, their activities, their complementarities, and their diversity are the starting points for our exploration of innovation processes in an innovation system framework. However, this approach should be accompanied by an analysis of the relationships and interactions that exist in the innovation process. All of these are partially or fully dependent on operational drivers, including the actors' capacity (financial and human capital) and avenues of interaction (Malerba 2007; Högselius 2005).

At all levels of an IS (e.g., the national and sectoral levels), interaction and relationships between agents are key for learning and producing, transferring, and using knowledge. As highlighted earlier, knowledge is the main asset and learning is the primary process in an IS context. The learning process involves different actors (both knowledge producers and knowledge users) at different levels in their various capacities. Thus, different modes of learning are important and should align with the capacity of existing actors and infrastructures. Two modes of learning that have been identified include (i) Science, Technology and Innovation (STI), and (ii) Doing-Utilization-Interaction (DUI). Both modes can be applied in integrated and systemic ways (Jensen et al. 2016). Generally, STI is dominant in developed countries with a high-quality R&D infrastructure and education systems. The DUI mode is recommended for developing countries with scarce resources and limited infrastructure. However, an ideal situation would be a mix of both, depending on what is needed and what is achievable.

From these perspectives, examining the concept of 'innovation systems' at different levels has the potential to allow us to examine how innovation can be integrated into the economic growth process and development in general. This can be achieved by analysing complementarities among actors within the system, technology dissemination and adoption mechanisms, the quality of institutions, and relationships so as to enable learning and the use of knowledge for wealth generation (Freeman 2002). These areas depend on policies and policy instruments that govern resource allocation, capacity building, and market structures (Rosenberg 1982; Chaminade and Lundvall 2019).

Despite the existing literature on the concept of 'IS' and its adaptation to different levels, it is somewhat challenging to adopt the concept in developing countries. Whilst it has been explored and applied in developed countries, this has taken place under the assumption that it can be replicated in developing countries. However, this has not been the case. The adoption of the concept of

'IS' is context-specific since it is a concept that is not subject to the notion that 'one size fits all'. Based on this disparity in how the concept can be applied and taking the current evolution of IS research into account, we note an emerging interest in exploring how the concept of 'innovation systems' can be adopted in developing countries. In the next section, I present a discussion of emerging innovation systems and identify the significant elements of IS adoption. To this aim, I focus on the different characteristics of emerging innovation systems and identify the key enablers for the development of innovation systems based on experiences from developed countries.

2.2. Emerging innovation systems

Innovation systems are not distributed evenly worldwide. For example, many developed countries have established, stable innovation systems at different levels (national, regional, and sectoral). However, in many other countries, particularly developing countries, this is not the case (Lundvall et al. 2009; Scerri 2016; Baskaran and Muchie 2017). The difference between developed countries and developing countries with respect to innovation systems can be found in institutional frameworks, policies, various actors' capacity, and the nature of development issues (Mytelka and Smith 2002; Malerba 2007; Lundvall 1998; Muchie, Lundvall, and Gammeltoft 2003). In developing countries, institutions tend to be weak and are subject to low levels of coordination. Rules and policies are less enforceable, industrial capacities are still limited, and financial resources are scarce. On the other hand, developed countries have more mature institutions, coherent policies, developed industrial sectors, and are able to raise financial capital. Under these conditions, we note that whilst developing countries may well be in the early stages of establishing innovation systems, developed countries (including many OECD countries) already have functioning innovation systems in place which they are further refining (Altenburg 2009).

Emerging innovation systems are innovation systems that are at the early development stage, where effort is made to put basic requirements in place. At this stage, work is generally done in areas of capacity building, resource mobilization, and resource allocation. Capacity-building work is done at both the individual level and the institutional level (Alkemade, Kleinschmidt, and Hekkert 2007). Moreover, interactions and relationship building between and within organizations take priority at this stage, since whilst different organizations may exist, many operate in isolation from each other. The

process of establishing all of these basic requirements to initiate an IS and building an effective innovation system is time-consuming and context-dependent. Many developing countries are currently undergoing this process whilst different scholarly and policy work is being done to reveal the different dynamics involved in the process (Muchie, Lundvall, and Gammeltoft 2003; Velasco-Malaver 2015; Fagerberg and Srholec 2008; Spielman 2005).

The current literature on 'Innovation Systems' acknowledges the fact that we must consider the peculiarities of developing countries whilst building innovation systems (Altenburg 2009; Mytelka and Smith 2002; Lundvall 2010). The literature emphasizes the idea that institutions should develop in response to prevailing economic structures, social conditions, and market systems. Thus, the building innovation systems needs to take the specific conditions where the IS is emerging into account, instead of merely copying the success stories from developed countries, which, of course, find themselves in a completely different context. However, these success stories can be a source of inspiration for learning about how the different stages in the IS construction process can be approached. Different development goals in the two settings should be considered; developing countries deal with poverty reduction, whilst developed countries deal with enhancing existing production systems and conquering bigger markets to enhance their wealth. In this context, the motive behind using IS is to enhance industrial performance and market extension, and to increase R&D activities. On the other hand, in some developing countries, the industrial sector does not exist or is still at the embryonic stage, and understandably, R&D capacity remains quite limited. Such conditions in developing countries do not allow us to follow the path taken by developed countries in building innovation systems.

Under these conditions, emergent innovation systems may lack several elements that are usually found in ideal innovation systems, hence the potential differences in innovation trajectories and facilitation mechanisms for knowledge transfer and use. This has compelled us to adjust our conceptualization of IS, so that it can be easily adaptable to the conditions found in developing countries. However, the extent to which the concept of an 'innovation system' needs to be re-conceptualized to respond to specificities of developing countries remains debatable (Lundvall 1998; Lall and Pietrobelli 2003; Muchie, Lundvall, and Gammeltoft 2001; Lundvall et al. 2009). Many developing countries remain faithful to implementing ideal innovation systems, since they have been conceived and have been shown to be successful in established economies. This has led to failure in many cases, but countries like Russia, India, China, and Brazil have managed to opt for National

Innovation Systems based on their own unique contexts and have made discernible progress (Djeflat 2015).

The implementation of NIS might be different in small and developing countries because of their limited capacity, limited resources, as well as the role of existing institutional and economic structures. Different factors can explain the progress that these countries enjoy; particularly, the availability of natural resources and a significant market size that large countries possess. In this context, the first steps one might take could include analysing the country's capacity building potential, establishing relationships, and demonstrating how learning capabilities are emerging within the country (Chaminade and Vang 2008).

The hurdles that an emerging innovation system may face cannot only be associated with local conditions. Note that the 'IS', as a concept, is quite broad and thus cannot be easily replicated or adopted. Scarce resources and limited skills to embrace a such broad and complex concept pose their own challenges. To overcome such challenges in emerging innovation systems, the 'IS' concept needs to be accompanied by other concepts/models that streamline the broader issues (such as establishing relationships and interactions between various organisations) inherent to the 'IS' concept. The Triple Helix Model, for example, is a model that potentially complements the 'IS' concept, since it can be used to explore how relationships and policies are formed and implemented by the main actors in the IS, namely universities, government, and industries. In the next section, I elaborate on the TH model in more detail and discuss how it complements the IS.

2.3. The Triple Helix Model

The Triple Helix Model can be defined as a network of University-Industry-Government relationships that can be used for policy advice and the exploration of potential roles of the three actors in network development, as relevant to the production, transfer, and use of knowledge and the incubation of new industries (Leydesdorff and Etzkowitz 1996; Leydesdorff 2012). The Triple Helix Model of University-Industry-Government was introduced to examine the depth and complexity of the innovation process. From this perspective, the innovation process is conceptualised as a recursive interaction system underlying the knowledge-based economy, and is thus deployed to enhance our exploration of the conceptual and empirical grounds of

knowledge-based development. It also provides a framework for investigating the empirical question of systemic functioning (Leydesdorff and Zawadie 2010). As it is conceived, the TH model allows for the exploration of relationships between its three different actors (university, industry, and government) and provides more precise identification of the functions that are performed in each of the spheres and how they are expected to be performed. In terms of innovation policies, the TH model allows us to explore mismatches and complementarities that may exist between institutional dimensions in the arrangement of its identified normative functions (Jacob 2006; Lawton Smith and Leydesdorff 2014).

These normative functions are (i) organized knowledge production, (ii) wealth generation, and (iii) organizational control (Lawton Smith and Leydesdorff 2014). The three actors build relationships that are expected to be interactive (with feedback channels) to accomplish these normative functions. The ideal interactions within the TH are expected to involve the active engagement of (i) universities in knowledge production, (ii) industries in using knowledge for wealth generation, and (iii) the government to provide an enabling operational environment as part of its organizational control function. However, the fact that each actor in the TH is assigned clearly defined functions, does not prevent joint actions and possibilities emerging where one actor can take over the function of the other for complementarity and mutual support. All these features are part of the broader 'IS' concept, which explains the importance of the TH model in understanding specific features of innovation systems.

The TH model is an analytical tool that has been described by several scholars (Etzkowitz and Dzisah 2008; Goktepe 2003; Benner and Sandström 2000) as a particularly relevant tool for developing countries and international agencies for organizing knowledge production and knowledge use for development purposes. This model advances the idea of an "entrepreneurial university" as a source of knowledge and skills that can drive development initiatives forward through a flexible circulation of human resources between universities, industries, and government agencies (Etzkowitz 2013; Etzkowitz and Leydesdorff 2000). The institutional setting is considered to be an enabler of this circulation, although, in most developing countries (e.g., African countries), institutions and policies remain problematic because of the weak collaboration between actors and weak policy implementation strategies (ACBF 2017). Low levels of institutional collaboration are, to some extent, a function of conflicting mandates and operations, which are a remnant of the replication of institutional structures harking back to colonial times. For example, replication of colonial-era institutional structures can be seen in some

university structures and in the educational curricula that is followed in British and Belgian former colonies, which have proven difficult to operationalize in these countries (Havas 2002; Sawyerr 2004; Etzkowitz and Dzisah 2008; Iizuka et al. 2015).

Although it is difficult to adapt the TH model to these contexts because of the institutional, structural challenges that exist in many developing countries, the model still offers up several fundamental principles which can be used to understand how the facilitation of knowledge use can be organized and the potential functions and roles that actors in the three spheres can play. It might be seen as a tool which can be used to operationalize the NIS framework, thereby informing us what should be done to make innovation a matter for development. The TH also allows us to explore how innovation can be implemented, since it includes components that are concerned with interaction and collaboration between the three spheres. In fact, these three actors are referred to as the core elements of the system in the NIS concept, too. In the NIS framework, interactive learning processes are fundamental to the functioning of the system. With its distinction between the different actors' roles and their interaction with each other, the TH model enables empirical exploration of the construction of a narrow national innovation system. It can be used as a tool for policy experimentation between the spheres and it can identify how policy instruments can be exploited to build synergies between the Triple Helix actors. Note that these actors are simultaneously the major agents of the NIS that can be categorized as either knowledge producers or knowledge users.

Despite the potential of the TH model to address specific issues related to policies and relationships within the IS, the TH does not capture technology and innovation integration at the different levels of economic structures. To achieve this requires purposeful adjustment of various levels of integration and control if one is to grasp competitive advantages at the various levels of economic structures (Porter 1990). The Value Chain Model provides an understanding of the integration of different practices at different stages for value addition and profit maximization (Fagerberg et al. 2018). In this spirit, the Value Chain Model can be used to support innovation systems and the TH model to examine technology and innovation integration at different levels. Researchers in this area have previously explored the co-evolution of innovation systems and value chains (see Lema et al. 2018; Jurowetzki et al. 2018; Crescenzi et al. 2014; Pietrobelli and Rabellotti 2011). In the next section, I discuss how the Value Chain Model is used in this thesis as a support

model to NIS and the TH model, as I explore how technologies and innovation trajectories can be organized in the Rwandan agricultural sector.

2.4. The Value Chain Model and innovation

The concept of 'value chain' captures a sequence of related and interdependent activities that are undertaken to bring a product or service from its conception, through different stages of production, to its final consumers. Value chains can operate at different levels, with Global Value Chains and Commodity Value Chains being the most popular. By means of industrial upgrading, commodity value chains specify mechanisms by which organizational learning occurs in trade networks (Gereffi 1999; Crescenzi et al. 2013). In the upgrading process, trajectories within value chain activities and organizational conditions are also specified. The concept of 'upgrading' refers to several kinds of changes that actors undertake to improve their competitiveness in the value chain. Upgrading can be for a product, a process, a function, or with respect to coordination. The upgrading can be within a value chain (intra-chain upgrading) or between value chains (inter-chain upgrading) (Gereffi et al. 2001). These various types of upgrading offer a framework that is relevant (i) to analysing how knowledge and skills are acquired and shared and (ii) to investigating how countries organize their development strategies.

Understanding how value chains work is essential for a developing country's industries and policy-makers, because the structure of a value chain has implications for the building of relationships, resource allocation, technology transfer, adoption operations, access to skills, and competence development (Gereffi et al. 2001; Lema et al. 2018; Chaminade and Vang 2008). Michael Porter (1985) has suggested an analysis of value chains that can be used to examine key value chain activities at different stages and interrogate how value chain actors are involved in undertaking these activities. Porter's value chain analysis approach categorises value chain activities into two main categories: primary activities and support activities. Primary activities include inbound logistics (primarily production activities) and outbound logistics (focusing on sales, marketing, and consumption). These primary activities require support activities, where technology and innovation play an important role. Through support activities, actors at different stages can acquire the skills and competencies that are needed for upgrading. However, this requires systemic functions and active interactions between value chain actors.

Research that explores the co-evolution between innovation systems and value chains is ongoing. Such research aims to examine how organizational structures in value chains provide opportunities for building production and innovation capacity in local industries. In particular, in the context of developing countries, several key questions need to be explored by this type of research. We do note, however, the pioneering work done by Lema et al. (2018) and Jurowetzkiet al. (2018) who pose the following two questions for developing countries: "Can a combination of value chains and innovations approaches help to foster understanding of trajectories of learning and innovation in developing countries? What are the conditions and dynamics involved?" Following this line of thinking, this thesis has used agricultural commodity value chains to explore how technology and innovation trajectories are organized across various value chain activities. This approach is informed by my desire to examine how knowledge transfer and knowledge use can be organized and sustained in emerging agricultural agriculture innovation systems.

2.5. Analytical framework

In this thesis, I have employed a combination of the National Innovation System Model, the Triple Helix Model, and the Value Chain Model in my analysis of dynamics in institutions, relationships, and associated policy instruments that are used to facilitate knowledge uptake (production, transfer, and use) for socio-economic development in Rwanda (Figure 1. provides additional details concerning key concepts). The NIS model was used as the overarching analytical framework to explore issues of organizations and structures for interactive learning process among actors for knowledge creation (co-creation), knowledge transfer (dissemination) and knowledge use. This framework was also used for institutional framework analysis and analysis of systemic interactions among stakeholders. The NIS model was used to analyse different elements at the national level (macro-level).

The macro-level analysis identified key patterns which were later focused on for the sector level analysis (i.e. the meso-level). This allowed me to set the stage for the exploration of key issues related to policymaking, technology, and innovation trajectories. The Triple Helix Model and Value Chain Model were used as secondary tools to complement the NIS Model with respect to the analysis of several issues. This was done to bridge the gaps in the NIS model (as the overarching analytical framework), since it did not capture the specific

issues of relationship building, policymaking, and policy implementation, whereas the complementary tools (the Triple Helix Model and the Value Chain Model) could capture such issues. Thus, these tools were used to explore issues related to the stakeholders' interactions with each other, policymaking in the agricultural sector, and technology and innovation trajectories. The Triple Helix Model was primarily used to analyse how key actors in the agricultural sector interact with each other and how they are organized to accomplish their roles in supporting innovation. It was also employed to explore how the function of organizational control is performed, particularly regarding the issue of interaction in policy formation and implementation. The Value Chain Model was used to explore how value chain activities and actors' interactions with each other to accomplish these activities are organized so as to allow the integration of technology and innovation at different stages of the value chain.

The overarching analytical framework and the complementary tools were used by applying the key concepts of 'dynamic capability', 'absorptive capacity', 'technology transfer', and 'policy learning'. These concepts were used to understand the inner workings of the NIS in a pragmatic way, based on major factors that explain key aspects of resource endowment, relationship building, interactive learning, systemic organization, and knowledge transfer and use. The concept of 'dynamic capability' engages directly with asset (resources) positioning, process, and the pathway that a company or a nation needs to follow to achieve wealth creation or to improve (build) its competitiveness in a rapidly changing environment (Teece, Pisano, and Shuen 1997; Teece and Pisano 1994). Based on these main components of the dynamic capabilities (resources, process, and pathway), the concept allows to examine how innovation performers (firm, nation, region, etc) mobilize and allocate resources, organize and manage their activities, and take different pathways to enhance their competitiveness (Pisano 2017; Linden and Teece 2018).

In the framework of innovation systems, the concept of 'dynamic capabilities' allows us (i) to examine work that is devoted to resource mobilization and resource allocation which are aimed at building innovation competencies and (ii) to investigate organizational and structural arrangements that are aimed at building relationships between actors and (iii) to map out the path dependency in the process. Based on the dynamism inherent to innovation systems, different capabilities are needed in different dimensions. Consequently, the concept of 'dynamic capability' is an appropriate concept since it captures how different steps are undertaken to address issues related to resources, organizational processes, and the pathways that are undertaken to enhance competency.

We also note that learning is the main process in innovation systems. Learning lies at the centre of knowledge production, knowledge transfer, and knowledge use to address societal problems. The concept of 'absorptive capacity', on the other hand, is crucial to understanding how the learning process takes place, based on a person's or organisations' capacity to acquire, process, and use knowledge/technology. The concept of 'absorptive capacity' is generally defined as the ability to identify, acquire, process, and apply knowledge/technology that responds to a demand or that fills an existing knowledge gap (Cohen and Levinthal 1990; Harvey, Jas, and Walshe 2015). Absorptive capacity exists at the individual level and the institutional level and is based on the initially-possessed knowledge and resources (human, financial, and infrastructure resources). In terms of knowledge, initially-processed knowledge plays an important role in determining a person's or organisation's learning capacity for new knowledge, whether they can use new technology, or even adapt new knowledge. Concerning resources, learning capacity depends on available means for R&D investment to produce new knowledge or use acquired knowledge (Cohen and Levinthal 1990; Camisón and Forés 2010). Thus, in the framework of innovation systems, the concept of 'absorptive capacity' can be used to explore the available learning capacity as well as the capacity for technology absorption. In the context of this thesis, absorptive capacity was explored in terms of education, R&D investment, infrastructure development, and avenues for interaction.

On the other hand, policy learning addresses how different best policy practices are adopted, applied, and integrated with the aim of improving performance and efficiency. This can happen with respect to innovation policies and associated public policies and policy instruments (for example, strategies and programs). Policy learning can take place in different forms, but it does require the capacity to learn. If a capacity to learn is not present, then unexpected results may arise (Borrás 2011; Borrás and Edquist 2013; Borrás and Højlund 2015). In this thesis, the concept of 'policy learning' was used in the context of the TH model to analyse (i) how policymaking for promoting innovation is performed and (ii) the practices that are being learned and how they are being integrated to build an innovation system in Rwanda.

To explore the knowledge transfer process, I exploit the concept of 'technology transfer', based on a new perspective suggested in the context of a knowledge-based economy. It has been argued that technology transfer be considered as a specific knowledge transfer process that depends on the way actors manage knowledge. In particular, this takes their absorptive capacity and their knowledge transmission strategies into account. This involves different

pathways along which the knowledge transfer process may proceed (Amesse and Cohendet 2001). Thus, in the context of the Value Chain Model, knowledge transfer processes are explored by assessing the knowledge demand, means of knowledge transfer (transmission strategies), and the sources of knowledge. All these are based on the structure of Value Chain activities as well as the organization of actors.

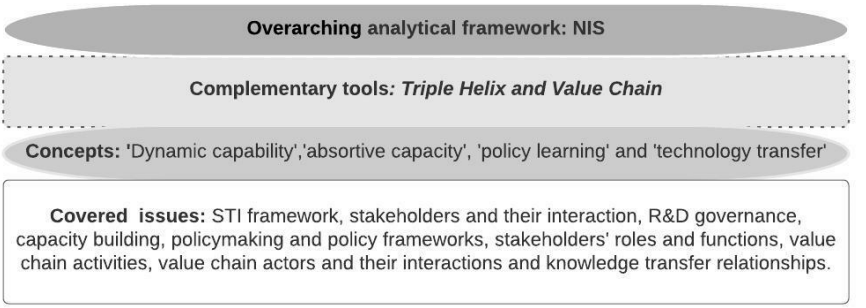

Figure 1: Description of the analytical framework used in this thesis.

3. Empirical context of the study

This section describes the empirical context of the study, including a general overview of the Rwandan socio-economic situation. Since the agricultural sector is used as a case study in this study, I provide a brief justification of why the agricultural sector is a suitable sector for this study and specifically discuss the Rwandan agricultural sector and its role in socio-economic development (in the country) with an emphasis on major crops. This serves as justification for choosing the commodity value chains used in my case study to explore how value chains can be used to promote innovation in the agricultural sector in Rwanda.

3.1. The Rwandan context

Rwanda is an African country characterized by its small size (26 338 km^2), high population density (around 552 people/km^2), a landlocked geographical location, limited natural resources, and a past history informed by colonialism and a more recent history marked by the genocide of the Tutsi people, in 1994. Rwanda has shown a high level of motivation and commitment to overcome the consequences of that tragedy and engage in national socio-economic development by taking up different development initiatives and being engaged in several regional and international collaborations. The Rwandan economy is primarily based on the service sector, tourism, and agriculture. The industrial sector can be classified as 'emergent' (NISR 2015; 2018). The development strategy that the country has adopted has been based no its natural resources, until recently. However, since 2000, great interest has been expressed in establishing a knowledge-based economy with proper exploitation and value addition to the existing limited natural resources. This strategy was clearly articulated under the framework of Vision 2020. Development investment in Rwanda is mainly loan and donation driven. However, internal capacities are being built to meet development demands, by engaging local development

actors and phasing out foreign direct investments (Murenzi and Hughes 2006; MINECOFIN 2012; UNESCO 2015).

The Rwandan context calls for specific approaches to the integration of knowledge as an input for national socio-economic transformation. This is urgently needed in Rwanda due to its high population density, limited natural resources, and high social expectation for advanced technologies to respond to development needs and market demands. Development actors perceive the use of research outputs and innovation to be two promising ways for the country to transition from a natural resource-based development to a knowledge-based development (NCST 2015). However, such an approach would call for systemic actions for facilitating the transition. Furthermore, one would need to secure the active engagement of different stakeholders and ensure that the available knowledge and technical skills reach end-users and respond to society's demands. This highlights the need for tools and mechanisms to stimulate and enhance interactions between the actors to produce and use knowledge. This can be achieved through an innovation system that includes responsive research and innovation initiatives. Coherent public and STI policies and collaboration among actors are key preconditions to building such an innovation system.

The Rwandan government has put in place several development plans and programs,[3] including Vision 2020, Vision 2050, and the National

[3] "The Vision 2020 is a reflection of our aspiration and determination as Rwandans, to construct a united, democratic and inclusive Rwandan identity, after so many years of authoritarian and exclusivist dispensation. We aim, through this Vision, to transform our country into a middle-income nation in which Rwandans are healthier, educated and generally more prosperous. The Rwanda we seek is one that is united and competitive both regionally and globally." (MINECOFIN 2012).

"The National Strategy for Transformation (NST1) is the Seven Years Government Programme (7YGP) that serves as a transition from Vision 2020 towards Vision 2050. This strategy is expected to lay the foundations for decades of sustained growth and transformation that will accelerate the move towards achieving high standards of living for all Rwandans." (MINECOFIN 2017).

"Rwanda's Vision 2050 articulates the long-term strategic direction for 'the Rwanda we want' and the enabling pathways to achieve this ambition. Rwanda now aspires to transform its economy and modernize the lives of all Rwandans. Vision 2050 serves as the critical planning and policy blueprint to guide the efforts of all players in Rwanda's development, including government, private sector, citizens, diaspora, civil society and faith-based organizations, development partners, academia and research institutions, and political parties. Preparation of Vision 2050 has considered global and regional development agendas to ensure harmonization of targets and indicators. These include: The Sustainable Development Goals (SDGs), African Union Agenda 2063, East African Community (EAC)

Transformation Strategy I. These programs recognize the importance of knowledge as a central element for national development. They also highlight the need for appropriate technologies that can cope with the high demand for scarce natural resources that is caused by a high population density (MINECOFIN 2012; 2017; 2020). Under these programs, research, science, technology, and innovation have been earmarked as priorities, and various initiatives have been undertaken through promoting higher education systems, setting up infrastructures, establishing policies and institutions, and mobilizing funds as a way of advancing knowledge for innovation and development (Gatete 2016; Gatare 2016).

Great strides have been made in the right direction, but sufficient research production is lacking, and the impact of research is still not readily evidenced. The lack of effective use of knowledge is mentioned as one of the root causes of the almost non-discernible impact of research on development in Rwanda. This is due to a lack of efficient tools and mechanisms which can be used to facilitate research and innovation uptake for development, thereby adequately responding to the Rwandan context (UNCTAD 2017; NCST 2020a). This situation demands that a thorough examination be conducted of institutional structures, policy frameworks, resource endowment, and resource use. Furthermore, the capacity to produce, transfer, and use knowledge through interactive learning processes between actors should also be subject to close scrutiny, so that we can suggest how systemic knowledge uptake can be organized and performed in the Rwandan context.

Vision 2050, and National determined contributions on the Paris declaration on climate change among other instruments. The Vision 2050 sets a new pathway that will lead the country to the living standards of upper middle income by 2035 and high-income countries by 2050. The Vision 2050 has overarching objectives of promoting Economic Growth, Prosperity, and High Quality of Life for Rwandans and is anchored around five pillars: **Human Development, Competitiveness and Integration, Agriculture for Wealth Creation, Urbanization and Agglomeration, and Accountable and Capable State Institutions."** (MINECOFIN 2020).

3.1.1. Brief description of the current Rwandan Socio-economic status

a. The economy and society

The Rwandan economy (in terms of GDP) is divided across agriculture (33%-28% of GDP, 2007-2019), industrial activities (16%-17% of GDP, 2007-2019), and services (44%-48% of GDP, 2007-2019). The agricultural sector is evolving into a more market-oriented model and moving away the old model of subsistence agriculture. It employs almost 70% of the working population and it also contributes to providing market opportunities, comprising a wide range of stakeholders and other economic activities (NISR 2018; 2019a). The sector offers business possibilities for different entrepreneurs in different domains, such as the emerging use of ICT in agriculture and the service sector. In contrast, the industrial sector remains at the embryonic stage but has shown promising progress in different domains, including manufacturing and agro-processing (NISR 2018).

The observable sustained economic growth in Rwanda is mainly due to exports (dominated by agriculture products) and the exploitation of natural resources. The vast majority of Rwanda's exports are primary products, most of them with limited added value. Over half of Rwanda's main export products are agriculture products (mostly coffee and tea), and minerals and metals. The use of locally-developed technologies and products has not been particularly noticeable, except until recently. We note that the Rwandan government has decided to invest in knowledge-based development, as reflected in Vision 2020, Vision 2050, and the National Strategy for Transformation I (NST I) (MINECOFIN 2012; 2017; 2020). This investment is supported by a number of policy actions/initiatives to build endogenous capacity and capabilities. The government has also encouraged the private sector to invest in local industries to enhance internal production systems.

In the same spirit, the government has established several operational strategies to drive forward the socio-economic transformation as expressed in Vision 2050 and the NST I. One important strategy is the 'Made in Rwanda' strategy and other schemes, including an in-house licensing program through the Rwanda Standard Board and the tax exemption status for specific equipment and products (for example, ICT equipment and certain agricultural products). Progress has also been observed in the advancement of R&D, where different bodies (including research institutes and centres of excellence) have been established to produce the knowledge and technologies that are responsive to local socio-economic needs (Gatete 2016; MINECOFIN 2017). Efforts to

advance R&D are still primarily mobilized through international collaborations (for example, the bilateral collaboration between Rwanda and Sweden). However, national funding schemes have been progressively established to support research, innovation, and academic-industry linkages. The establishment of centres of excellence is one of several noticeable actions taken by the government and its international development partners, including the World Bank.

In addition to achieving sustained economic growth, Rwanda has made much progress in improving people's livelihoods. The education system has undergone positive changes, with access to education for all Rwandan citizens. Currently, Rwandans have access to free education for their basic education, framed under the Nine Years Basic Education (9YBE) programme and the Twelve Years Basic Education (12YBE) programme. In addition to the provision of basic education, the higher education system is expanding. A growing number of institutions (31 higher education institutions have been accredited as of 2019), and technical schools (8 Integrated Polytechnic Colleges) have been established (MINEDUC, 2010; WDA 2018; HEC 2019). However, the education sector still strives to offer high-quality education that meets the labour market's demand and global competition, in terms of technological advancements and market extension. The promotion of 'education for all' and support for higher education institutions can be seen as a primary input for enhancing Rwanda's knowledge absorption capacity, since these educational inputs enable citizens to acquire a basic understanding of new technologies and technological changes in different domains (for example, in the use of ICT tools).

All the above-mentioned efforts are aimed at improving the living conditions of Rwandans and at enhancing the skills of a labour force that can contribute to the country's continued development. According to NISR 2018, a significant proportion of the population is below the working age (0-15 years old, 43% of the total population) and the majority of the working age population (75%) has only a primary school level of education. A large proportion of the working age population is engaged in farming activities, whilst most highly skilled workers (secondary education and university level) work in paid non-farm activities. Approximately 84% of employed university graduates are employed in paid non-farm jobs whilst 54% of secondary school graduates also hold paid non-farm jobs. It has been noted that the proportion of workers in wage-farm jobs is increasing over time, but their level of wealth creation seems to be worsening. Despite this, Rwanda has experienced an

overall reduction in poverty. The proportion of Rwandans who live in poverty was reduced from 46% in 2010/2011 to 33.6% in 2016/2017 (NISR 2018).

Although improvements have been made, the portion of the population living in poverty remains significant. Consequently, effective strategies for significant poverty reduction are needed. The current development strategies (Vision 2050 and NST I) need to articulate clear mechanisms and comprehensive roadmaps in different dimensions to reduce poverty levels. Among other things, one should address the identified development pillars and set out priorities under these programs. A 'knowledge-based economy' and 'agriculture for wealth generation' have been identified as key pillars and priorities under these programs. Thus, it is of capital importance that we understand how knowledge production and knowledge use can be fostered in Rwanda. It is particularly relevant to enhance collaboration between knowledge producers and knowledge users in earmarked potential socio-economic sectors, including the agricultural sector. In the following sections, I discuss the status of the Rwandan industry sector and the higher education system. This is followed by a presentation of the agricultural sector as a case study, where I discuss its potential for using knowledge and innovation to advance Rwandan socio-economic development.

b. Industrial sector

The industrial sector in Rwanda is at a very early phase of its development and its contribution to the economy remains low compared to other sectors of the economy. It contributes around 16% of the national GDP and employs approximately 4% of the working population (MINICOM 2011; NISR 2019). It is one of the Government of Rwanda's aspirations to make the industrial sector a more significant contributor to the economy. It is expected that industries will contribute approximately 26% of GDP by 2030 (MINECOFIN 2017; 2020). The plan for industrial sector development is based on three main pillars: (i) domestic production, (ii) export competitiveness, and (iii) enabling environment. Domestic production focuses on diversification and value addition to different products to meet the local market demand. Export competitiveness focuses on increasing the quality and quantity of products for export to regional and international markets. Enabling environment supports the other two pillars. It entails the formulation of policy and regulations, and governance of the industrial sector. Moreover, it includes facilitation for access to infrastructure, technology, and skills (MINICOM 2011).

Access to technology and skills remains a challenge due to a lack of qualified personnel and technologies in Rwanda. According to the situation analysis

provided in the national industrial policy, the skills gaps in different industrial clusters are high. The skills deficit can be found at different levels, however, it is most acute among technicians, estimated at 60% of the requirement. The most affected economic activities are tourism, construction, and the art/craft sector, they have less than 30% of the skills required for technicians. In addition to skills gaps in technicians, there is scarcity of managers in many industries in different economic sectors. The agricultural sector is the most affected sector by the lack of skilled managers (program developers and executives, mainly), only 20% of managers had the needed managerial skills. This skills gap makes it challenging to develop the industrial sector. This gap is connected to the claim that the type of education that is provided in Rwanda is not responsive to these industries' demands. The same situation is found in the domain of technology gaps, since the internal capacity for technology development remains low in Rwanda (MINICOM 2011). All of these challenges have forced the Rwandan industrial sector to focus on basic processing and manufacturing activities. This approach is dominant in the agricultural sector, mainly for food and beverage production. However, the construction sector is also relatively advanced in terms of industrial activities (NISR 2019a).

Present priorities to enhance Rwandan industrial capacity focus on sectors that are currently in operation (manufacturing and construction, for example). These priorities aim to enhance building capacity for local industries so that they can develop their own technologies or successfully adopt imported technologies. This is expected to be achieved through collaboration between industries, research institutions, and universities. A strategy for 'learning at the workplace' has been established following the Skills Assessment and Action Plan (SAAP). This survey was conducted to assess skills gaps and possible initiatives that can be undertaken to fill those gaps, thereby ensuring sustained industrial sector development (MINECOFIN 2017).

The collaboration among actors (industries and research organizations, in particular) is expected to be built on mutual interest and win-win arrangements. However, investment in industrial and R&D activities remains a challenge for the government and the private sector alike. One strategy has been to attract foreign investors to invest in local industries and to engage international donors in this form of collaboration. Under this framework, a special economic zone (SEZ) was created in Kigali to host different industries. These industries could acquire the space that they needed and access basic infrastructure (for example, water and electricity supplies). This special economic zone is expected to host industries, universities, and science parks (Steenbergen and Javorcik 2017).

With this strategy of establishing an SEZ (a so-called 'space-based strategy'), it is expected that collaboration between industries and knowledge production institutions will increase, and technological capabilities for local industries will be enhanced. Among the first industries to be established in this area include manufacturing, ICT assembly, agro-processing, construction, and biotechnology. Although the creation of the special economic zone in Rwanda is a high-profile project, other regions in the country still face the challenge of how their industrial capacity will develop. Notwithstanding this, these regions are the leading producers of many key raw materials used in agro-processing and construction. Moreover, the expected collaboration between industries and knowledge institutions has yet to be realised, and it remains unclear how the current strategy that is built on geographic proximity will facilitate the expected collaboration without clear funding strategies and systemic integration of R&D in industries. Note that the importation of technology remains the key strategy for industrial development.

Ideally, space-based strategies in knowledge-based development process are ultimately based on knowledge spillover activities that are likely to be fostered by geographic proximity, the presence of a working infrastructure, knowledge production capacity, absorption capacity, and interactions industries and knowledge systems. In some developed countries (for example, Germany and Sweden), science parks and innovation hubs have become key instruments for knowledge spillover in industrial development. This is made possible because many industries are contributors to R&D activities, through funding and infrastructure development (Grillitsch and Nilsson 2017; Funke and Niebuhr 2005). With the active engagement of industries in knowledge production and clear articulation of their demands regarding R&D efforts, knowledge spillover can occur and ultimately contribute to industrial development and, by extension, the NIS development. The Rwandan context, as presented above, seems to be different from the ideal scenario of creating beneficial relationships between industries and research systems to address community problems. Major issues that are present in Rwanda are primarily (i) limited capacity (in terms of financial capital and skilled human capital) and (ii) low levels of collaboration between industries and knowledge systems (i.e., universities and R&D organizations).

As articulated in the Rwandan industrial policy, there is a need to understand how one might establish an enabling environment for beneficial collaborations which can foster the development of industrial sector in Rwanda and ultimately, improved the overall performance of the NIS. Some steps have been made to put in place structures that can contribute to coordination efforts,

the mobilization of resources, and the building of competencies. The establishment of the National Commission of Science and Technology and the National Industrial Research Agency are among the key organizational steps made by the government to foster collaboration, coordination, and set out clear strategies for resource mobilization and resource allocation (Paper I provides a more detailed discussion of the relevant institutional frameworks). Even though the government has made these steps, it is essential that we understand how they contribute to advancing innovation. We must then examine the associated dynamics to achieve sustainable industrial development and an effective NIS.

c. The higher education system

In 1963, the first university was established in Rwanda with 16 lecturers. The initial student enrolment was 16 students. Most of the lecturers were foreigners, as was the university's management team. The development of Rwandan higher education and research institutions followed at a very slow pace, involving only a few local actors. Until the early 1990s, less than ten higher education institutions were registered and operating in Rwanda. A considerable growth in the number of higher education institutions (awarding degrees and diplomas) occurred during the period of 2000-2015. This period of growth was dominated by private universities (UNESCO 2015; Simiyu et al. 2010). However, the rapid increase in the number of higher education institutions should be put into perspective by considering the size of these institutions (universities) in terms of their enrolment numbers, the number of lecturers and researchers that they employ, and their physical infrastructure. Most of the institutions that opened during 2000-2015 are small institutions and have limited resources (in terms of their human and financial resources). For example, in 2019, 31 higher education institutions were accredited to operate in Rwanda with a total student population of 86,206 students. This student population increased from 47,406 students in 2008, whilst the number of institutions increased from 23, in 2008, to 31, in 2019. From this student population increase, it can be deduced that the average student population per institution (university) was 2061 in 2008 and 2873 in 2019 (i.e., 28% increase). However, the overall increase of the student population was 45% (MINEDUC 2012; 2019). This situation shows that whilst progress has been made, most Rwandan universities are small and their impact on society development is hardly observable, even though their total number has increased. I argue that strategic choices need to be made with respect to academic programs, including teaching and research, that are offered at these institutions. This

includes their engagement with the rest of society, particularly with industry, and with the private sector, in general.

The higher education system in Rwanda is dominated by institutions that offer bachelor's degrees. Advanced research training programs, including PhD-level research programs are not yet well established. The same situation is found for the MSc degree. In 2019, less than 5% of the total student population (86,206 students) were master's degree students. Only 0.1% of the student population were PhD-level research students (MINEDUC 2019). Although enrolment in research training programs remains low, the period of 2000-2015 marked a turning point in the development of many universities with respect to internationalization and training for higher research degrees. Note too that several centres of excellence were established during this period. Local, regional, and international research centres of excellence were launched, and innovation of sorts could be found at centres for research initiatives. Universities and research institutions started to implement mechanisms to promote innovation and industrial research. Innovation hubs and incubators were also set up during this period.

Even though the number of higher education institutions appears to be relatively high, there have been issues regarding the efficiency and quality of the education that is provided at many of these institutions. In response to this, work has been done to ensure efficiency and the provision of high-quality education in the higher education system in Rwanda. This was done to increase the critical mass of educated people who can respond to labour market demands and enhance the innovation absorptive capacity of the Rwandan population. The merger of all public higher education institutions in 2013 into one public university (University of Rwanda) is one of the actions that were taken by the government so as to ensure resource efficiency and strengthen the provision of quality higher education. However, the achievement of the expected efficiency and quality goals might require more than just structural arrangements. More effort in resource mobilization, the provision of enabling research environments (in terms of policies, procedures, and regulations), and the establishment of a research culture and a culture of collaboration need to be continuously made. Since its inception, the University of Rwanda (UR) has graduated 49,477 students, of which 2,053 were at the MSc level and 9 at the PhD level. Student enrolment in 2020 was 25,084 students at all levels, with 95% at the undergraduate level. In terms of staff numbers, the university had 1952 active staff in 2020, 68% of which are academic and research staff members. 36% of the staff are administrative and support staff. Only 26% of the academic and research staff hold a PhD degree (UR 2020). These figures

indicate that there is a need to enhance research education programs (PhD) and the current researchers' capacity. Moreover, the private universities in Rwanda are relatively small (in terms of student population, human resources, financial resources, and infrastructure) compared to UR. Consequently, they might need to develop strategic plans that would increase their relevancy and their potential to contribute to the development of Rwandan society. One option they might consider is to optimize the use of their resources and focus on specialized programs that are identified as relevant to specific disciplines, economic sectors, or industrial clusters. Such a strategy would require enhanced interactions and collaborations that go beyond traditional research collaborations (like academic publications and participation in meetings/workshops). More engaging interaction and collaboration strategies should be explored.

Despite all of these efforts, the higher education system in Rwanda can be regarded as a teaching system with a low research impact. Most of the programs at Rwandan universities are teaching-based, and the infrastructure that is available at these universities is primarily set up for facilitating teaching activities. However, at some universities, there is a high interest in research and different initiatives have been adopted to establish environments that are conducive to conducting research. For example, at the University of Rwanda, eight centres of excellence have been created with adequate research facilities for applied research and PhD candidates training. Nevertheless, human capital remains a limiting factor with respect to performing high-quality research because the number of staff who hold research-based degrees remains low (only 21% of researchers in Rwanda hold a PhD degree, reference period 2015-2016) (NCST 2020b). A number of technical education programs that are aimed at addressing industrial problems were initiated in 2008. These programs, in conjunction with the establishment of the Work Development Agency, later evolved into the Rwanda Polytechnique and different TVET programs (UNESCO 2015; RP 2018). These programs focus on producing skilled graduates who can meet the needs of the labour market, particularly industry's needs. Specialized programs were developed based on national industrial priorities. Nevertheless, the collaboration between industry and higher learning institutions is not yet noticeable. Notwithstanding this problem, these programs can produce skilled graduates who are able to respond to industry's specialised labour demands and general labour market needs.

Many Higher Education Institutions (HEIs) in Rwanda have focused on teaching different disciplines based on traditional modes of theory-based courses. This approach provides students with only a limited exposure to

industry and the social problems that Rwanda is faced with. This is not only true for the above-mentioned teaching approach, but we note that the third mission of these institutions, namely technology transfer and community engagement, appears to be somewhat neglected. This unfortunate state of affairs is, to some extent, due to the low engagement of some universities (private universities, in particular) in R&D activities that can produce transferable technologies/skills. Limited financial capacity, a lack of adequate infrastructure, and a lack of qualified researchers are among the common reasons why there are low levels of engagement in R&D activities at many universities (NCST 2020b). Moreover, the career track for lecturers that these universities offer is also a factor. Some staff members hold what are primarily teaching positions, where research is considered as an extra duty, not a core activity. With this approach, it is difficult for these staff members to realize the expected role of higher education, namely, to contribute to industrial and societal development. Note that this expected role is explicitly mentioned in various development strategies, including Rwanda's Vision 2050). However, it is important to also note that the current development of the higher education system has, to some extent, increased the critical mass of educated people in Rwanda, thus increasing the technological absorption capacity of the community. For example, the use of mobile phones and associated technologies have increased due to the high increase in the level of ICT literacy in the population.

Taking the situation described above into account, we may well ask whether this provision of education can give rise to the desired results in the country or whether there are alternative ways to give rise to the desired results. It has been argued that the way universities operate is important, and, in many ways, the way that they operate defines their impact on society's development. Generally, a university's operations are a function of the university's governance, leadership, structures, and resources. Human and financial resources are key resources for universities, as is their physical infrastructure. Furthermore, the way researchers are recruited, retained, and incentivised also plays a role in determining what impact a university might have on society. The mobility of researchers is another important factor for a university's activities as well as its collaboration with its partners. All of these require an enabling university system that is comprehensive, dynamic, and flexible (Benner, Malmberg, and Schwaag Serger 2021). The higher education system in Rwanda suffers from several challenges that hinder its ability to enable the recruitment and retention of researchers and the incentives and mobility that the system currently offers.

The recruitment process at public HEIs in Rwanda is a long and complex administrative process that is governed by public administration rules. Under the current process, a thorough scrutiny of a job applicant's research and academic competencies is not predictable because research and academic competencies are broad in their nature and require a high level of flexibility. In many cases, such a long and complex recruitment process does not enable the recruitment of the most talented academicians and researchers available on the market. For example, public universities do not have the flexibility to offer tutorial assistantship positions (or research assistantship positions) to their best graduates. However, these individuals are potential future researchers. In a place like Rwanda with under-developed research training programs, one might expect that talented individuals would be highly sought-after. Not only does the current recruitment system not offer flexibility for the recruitment of highly qualified and talented researchers, but these administrative complexities do not allow for the provision of attractive incentives to productive researchers. Besides academic promotions, there are no other real incentives on offer that can attract researchers to many Rwandan HEIs. Thus, it is a challenge for these institutions to retain highly qualified staff. This claim is supported by the observation that the turnover in the research staff at many HEIs is relatively high. For example, the University of Rwanda is the largest public university in Rwanda. However, 18% of its staff have left during the past five years, and only 4% have raised their qualification to the PhD degree level (UR 2020). Due to this high turnover, the university leadership has been dominated by acting positions (not permanent appointments). Consequently, visionary leadership with regards to establishing a thriving research community is lacking. Instead, the university's leadership is characterised by crisis management and a search for short-term solutions. This significantly affects teaching and research productivity at the university and diminishes the potential impact that the university can make on the rest of society.

HEIs in Rwanda, as mentioned above, are more teaching-oriented and thus place low emphasis on research. This is noticeable with regards to research funding and the development of a research culture development. There is only a small budget (7.8% of the total GERD, with a total GERD of ~44,457,114 USD (0.66% of GDP) in 2016) that is allocated for research at many HEIs in Rwanda. Private universities primarily generate an income tuition fees and thus invest less in research than in their core teaching activities. In reality, their research budgets are only funded through donations or, in some cases, through grants (NCST 2020b). For public universities (e.g., the University of Rwanda), there is no specific fund that is allocated for research

activities. The research budget is expected to be maintained by international collaborations. Unfortunately, the use of this budget is not adequately facilitated due to the complex administrative system. The complex administrative system can cause delays in research activities or, in some cases, lead to the production of low-quality research because of a lack of facilities, including good quality research equipment. Unnecessary complexities in the administrative system are present in the university's procurement processes, staff recruitment procedure, access to budgets, and the enjoyment of academic benefits (and rights) from grants (for example, research allowances and travel grants).

Due to their limited budgets and the research performance appraisal mechanisms at different universities in Rwanda, much of the research that is conducted is theoretical and is primarily aimed at producing academic publications. Many universities focus on academic publication as the key measure of research performance. However, comprehensive frameworks that include other performance indicators, including innovation, policy impact, IP registration (for example, patents, utility models, and industrial design), have been introduced at some universities which aspire to achieve research excellence (for example, the University of Rwanda). Suppose one solely adopts a performance indicator model that recognises only theoretical research and a strategy that emphasizes publication as a measure of research performance. In that case, it becomes difficult to collaborate with industry because industry in Rwanda is interested in applied research that responds to their demands. Moreover, industry actors might not be interested in investing in research at a university because there is no assurance that these investors will get the research results they are looking for or generate competencies that can solve specific problems in their businesses. Without collaboration between industry and university, the role of the higher education system with respect to the Rwandan NIS will remain but a minor role. However, the role of HEIs in Rwanda can be enhanced if strategies for collaboration can be put in place. Doing so requires a proper diagnosis of the inner working of the NIS and how interactions can be enhanced in mutually beneficial collaborations. Furthermore, answers must be provided to the question of how such collaborations can be sustained in the long term.

3.2. Why the agricultural sector?

Worldwide, agriculture is considered to be a core economic sector that possesses the potential for social transformation, particularly in developing countries. Agriculture in most developing countries is the primary source of income and food for a large part of the population. African countries have relied on agriculture for a long time as part of their development strategy. Traditional agriculture practitioners practiced subsistence agriculture with surplus production being sent to market. In the past, the soil and climatic conditions favoured this approach since it could use natural methods of soil fertilization and the country enjoyed less extreme weather conditions. However, with the population increase and high demand for land resources, the agricultural sector faces several challenges requiring a different approach to ensure that it will continue to contribute to society's development (Juma 2015).

The shift from traditional, subsistence to modern agriculture has evolved differently across Africa, depending on the individual country's context. Over time, high demand for food resources, land degradation, and climate change have forced many farmers and government officials rethink their practices and strategies for the development of the agricultural sector. These changes have led to a modernized agricultural sector with a high level of technological application. The availability of the necessary technologies, skills, and resources are among the primary factors that drive this change (Juma 2015). Agricultural mechanization, agro-biotechnology, agro-processing, and agribusiness are among the core skills in demand if the agricultural transformation is to proceed (Gahakwa et al. 2014). Although the demand for skills has been identified, linking the development of these skills to their transfer/use in reality remains a challenge. It has come to the attention of different stakeholders that collaborative and mutual learning initiatives may serve as a means for skills development and their application (Schut et al. 2015). Hence the need for a systemic approach which includes multi-stakeholder engagement mechanisms.

The need for skills development and application has highlighted the relevance of research and innovation as core elements of the development of the agricultural sector. Different developing countries have invested in agricultural education and research to ensure the production of needed knowledge and skills. Research institutions and academic institutions have been established, as well as centres of excellence. Once stakeholders realized that there was a need for specific solutions to the specific problems that are faced in the

agricultural sector, then the concept of 'innovation' was taken more seriously (Juma 2015; Ansoms 2009; African Union Commission 2014). The integration of innovation within agricultural sector practices has not taken place at an even pace across every African country. Some countries have made considerable progress, whilst others have lagged behind. Thus, it is essential to know (i) how innovation process can be facilitated in the context of emerging countries and (ii) how knowledge (scientific, technological, and traditional knowledge) can play a role in transforming the agricultural sector. Rwanda is a country that has striven after establishing modern agricultural practices that contribute positively to the country's socio-economic development.

3.2.1. The case of Rwandan agriculture

Rwanda is a developing country that has been trying to catch up with modern agri-technological developments. The agricultural sector in Rwanda contributes to the national socio-economic performance through income generation and the provision of food to the Rwandan population. This sector is also responsible for exporting several commodities including coffee, tea, and horticultural products (MINAGRI 2018; MINICOM 2013). For a significant period of time, the agricultural sector has been based on subsistence production that has used traditional farming practices that are primarily linked to traditional (indigenous) knowledge. This type of agriculture (if practised across the whole country) would no longer meet the current demand for food because the population has increased and the market for agricultural products has grown. In conjunction with the increase in food demand, another driving force for change in this sector was several technical problems that traditional methods could not solve. These problems included diseases and pests, the poor performance of certain crop varieties, a lack of a reliable water system, and the lack of effective post-harvest systems. Modern technologies have been imported to address these problems, despite the fact that many farmers cannot afford them (Mbonigaba 2013).

The need for affordable and responsive technologies in the local context has stimulated the government to collaborate with its development partners (including donors, civil society, the private sector, and NGOs) and establish national initiatives that are aimed at finding solutions that are easily accessible and affordable for local farmers. Consequently, the country has been forced to build Science, Technology and Innovation capacity in the agricultural sector. This has led to the establishment of research institutions that aim to develop relevant agricultural technologies and find solutions to local problems. These

research institutions are coupled with the integration of agriculture in education systems, both at the technical and research levels. An example of this was the founding of the Rwanda Agriculture Research Institute (ISAR) in 1992. The institute later evolved into the current Rwanda Agriculture and Animal Resources Development Board (RAB) in 2010. However, the Faculty of Agriculture (FACAGRO) at the former National University of Rwanda was the first higher education institution established in the field of agriculture in 1963 (RoR 2010; 2013). The education system's focus on agriculture has increased over time. Currently, both private and public universities offer agriculture as a major subject. Several agricultural technical schools have been established as well. In addition to this, 'innovation and entrepreneurship' has become a compulsory subject at these institutions and within the Rwandan education system in general. Its status as a compulsory subject has increased interest in technology transfer initiatives and the country's farmers' engagement in knowledge production, transfer, and use.

In addition to building internal capacity with respect to agricultural research and education, the Rwandan agricultural sector itself has made a concerted effort in developing policies and agriculture development strategies. The agricultural development strategies that have been adopted in Rwanda profile agriculture as an important socio-economic sector, based on its interconnection with other economic sectors, including industry, business, and the service sector, as depicted in Figure 2. This also implies a high degree of diversity in stakeholders who hold different roles, which can be leveraged to advance the sector. Major stakeholders include farmers, researchers, industries, policymakers, Non-Governmental Organizations, and Civil Society Organizations, amongst others.

Based on these potentials, this thesis uses the agricultural sector in Rwanda as an ideal entry point to examine how knowledge uptake can be fostered in the Rwandan context. This assumption also builds on the fact that the agricultural sector is earmarked by the Rwandan Vision 2050 as one of its five key pillars and by the national STI policy, which identifies the agricultural sector as a key sector for knowledge production, transfer, and use. The same is confirmed by UNCTAD's (2017) STI policy evaluation; among the 12 priority sectors identified by the STI policy, agriculture was among the best performing sectors. Thus, a complete understanding of the policy and institutional dynamics in the agricultural sector in Rwanda can provide insight into how sustainable mechanisms for the facilitation of knowledge uptake for socio-economic development can be successfully developed. The agricultural sector offers us the opportunity to cover a wide range of actors and

operations/interactions, which can serve as a reference for other sectors and the country as a whole. Several studies that are thematically related to my research have been conducted in other places of the world, and it is noted that the use of the agricultural sector as a model is a promising option. Examples of such research have examined the USA, Burkina Faso, and Colombia, just to mention a few (Nelson and Phelps 1996; Velasco-Malaver 2015; Windinmi 2016).

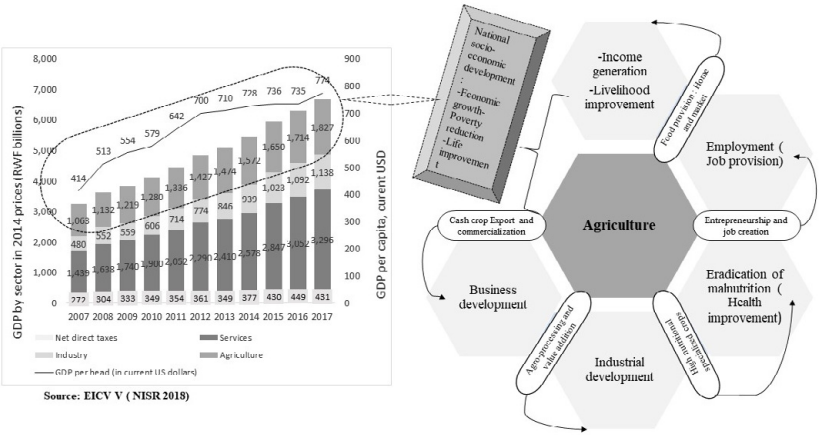

Figure 2: The position of the agricultural sector in the Rwandan socio-economy.

3.2.2. Agricultural production in Rwanda: An overview

The Rwandan agricultural sector is currently evolving from a subsistence farming model to a market-oriented agricultural sector. Specialized programs have been put in place to promote practices that increase production. The Crop Intensification Program and Land Use Consolidation are major national programs that have been implemented to improve agriculture in Rwanda (USAID 2014). Agricultural production in Rwanda focuses on both staple foods and cash crops (industrial crops). Staple crops are mainly seasonal and are grown in different parts of the country. Cash crops are mainly coffee and tea, which are perennial and grown in specialized areas. These areas satisfy these crops' soil and climate requirements. The key staple foods in Rwanda are

potatoes (Irish potatoes and sweet potatoes), maize, cassava, and rice (see Figure 3).

The north-western part of the country is one of the country's most productive regions, with Irish potatoes as a dominant crop, whereas cassava is the major crop in the south. Bananas are prevalent in the eastern part of the country, together with livestock activities (NISR 2019b). Concerning cash crops, coffee is mainly produced in the south, whereas tea is mainly produced in the north and west of the country. Both tea and coffee are the main products for agricultural export (Figure 4), in addition to a number of emergent horticultural products (Diao et al. 2014). Tea exports have increased over time, including primarily semi-processed products. With respect to all of these agricultural products, there is a high level of interest in processing these products and thereby adding value to them. This will add to product diversification and enhance the performance of the agricultural sector. This has been achieved by promoting the specialization of commodity value chains and by promoting agro-industries.

Based on the government's interest in promoting agricultural commodity value chains as a potential policy instrument that can be used to channel interventions and organize actors for the agricultural development, I have closely examined key potential commodity value chains to explore how the activities of knowledge production, knowledge transfer, and knowledge use are organized and executed by value chain actors. To this aim, I examined one staple crop value chain and one cash crop (industrial crop) value chain in one of the country's most productive regions (the north-western region) as exploratory cases. Irish potatoes and tea were selected based on their high level of production and diversity in actors. Irish potatoes are the most productive staple crop in the north-western region of Rwanda (see Figure 3). Tea is a key cash crop in the same region that enjoys an advanced level of value addition, a high rate of export, and is grown on a large scale (see Figure 4).

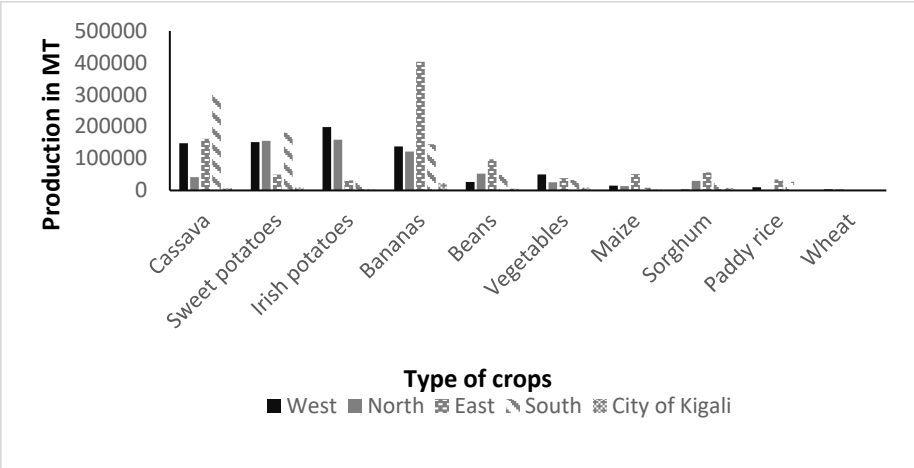

Figure 3: Production figures of major crops per province in 2019.
Data source: National Agriculture Survey (NISR 2019b)

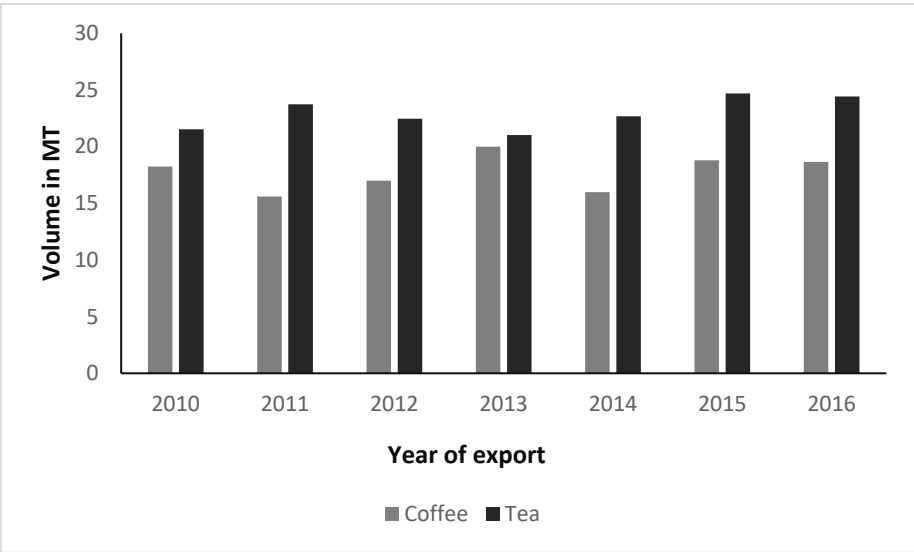

Figure 4: Variation in tea and coffee exports over time .
Data Source: World Bank 2017

4. Methodology and research design

4.1. Description of the research design

This research project used the case study approach as its general research strategy in its examination of the Rwandan agricultural sector. The case study approach used in this research project can be generally described as a systemic approach to investigating a claim in a specific context. The investigation that forms part of a case study can follow either a tracing process or it can focus on compiling empirical evidence with respect to the claim that is being made. Either of these approaches is adopted to explore and understand a phenomenon in a particular context (Bennett and George 2005). According to Stake (2000), the identification of a case study follows the specificity of the case and the inquiry to be explored and considers a more explorative question, not just as a descriptive one. For this research project, the case study approach was deemed suitable for exploring the claim that *the facilitation of knowledge uptake needs contextualized frameworks if it is to contribute to national socio-economic development in a developing country like Rwanda*.

In addition to the above, this study used a pragmatic approach in its response to the research questions. More specifically, it used a mixed-methods approach to explore practical problems in relation to the organization of knowledge production, knowledge transfer, and knowledge use for development in Rwanda. During the research process, a number of social, economic, historical, and political contexts were taken into account. A pragmatic research philosophy suggests that inquiries and events can be assessed through critical reasoning in light of their practical consequences (Shields 1998; Giacobbi, Poczwardowski, and Hager 2005). The approach used in this thesis was based on the contextual realities of Rwandan society's problems, demands, existing initiatives, plans, and the Rwandan people's aspirations.

In my exploration of contextual realities, I integrated a number of different research tools and methods in my examination of complex phenomena in different dimensions. The issues of (i) building of a NIS and (ii) how it can facilitate knowledge uptake were explored as complex and multidimensional phenomena that require an integration of different tools to understand the underlying process and the dynamics involved. From a pragmatic research perspective, the study employs an integration of NIS as the main analytical framework and two associated complementary tools (TH and VC) at two levels of analysis (the macro-level and the meso-level) to capture different patterns in the process of knowledge production and knowledge use. In doing so, the study integrates both inductive and deductive[4] approaches and uses collected data in its examination of how the national innovation system is being constructed in Rwanda and how it can serve as a framework for organizing the use of knowledge for the benefit of socio-economic development in Rwanda.

A contextual understanding of the NIS construction process and associated policy actions demand realistic and pragmatic approaches. These approaches can be used to explore how social, economic, and political dimensions can be interpreted and integrated into the process of bridging the gap between knowledge production and knowledge use in Rwanda. Data was collected based on local realities, particularly with reference to prevailing public/political, economic, and social structures. How the research and education systems, the business sector, and the government itself are structured were key determinants of how the data was collected and informed the associated analysis. This enabled an understanding of the dynamics (cause and effects, pathways, limitations, actions, and alternatives) inherent to the IS and gave rise to several options on how different issues can be approached.

Empirical evidence was used to examine the case study. For this research project, as in many other qualitative exploratory studies, both primary and secondary data were used to address the main research question and the associated sub-questions. The main research question and its sub-questions are addressed through four independent papers. The four papers use empirical materials that were collected by using mixed methods, including semi-

[4] Inductive reasoning (or analysis) observes patterns in specific cases to infer conclusions about general rules. It refers to approaches that primarily use detailed readings of raw data to derive concepts, themes, or a model through interpretations made of the raw data by a researcher. Deductive reasoning (or analysis) applies general rules to make conclusions about specific cases. It refers to data analyses that test whether the data is consistent with the prior assumptions, theories, or hypotheses that are identified or constructed by the researcher (Eisenhardt 1989; Thomas 2006).

structured interviews, data mining, and a systematic document review and literature review.

4.1.1. Selection of case studies and profiling

According to the criteria for identifying and choosing a case study suggested by Stake (2000), the choice of using a case study in this research project was based on the specificity of the case and the integrity of the system that was to be explored. The Rwandan case for NIS development was considered to be an instrumental case study because it provided information that was used to examine the integration of the concept of 'NIS' in the context of a developing country. This approach gave insight into the NIS construction, which other researchers can build on as they explore them in developing countries with a similar or near similar context to Rwanda. The agricultural sector and commodities value chains are informative regarding interactions between farmers and other stakeholders that are relevant to innovation development. Information from the agricultural sector and specific commodities value chains allows one to better understand how knowledge transfer and use can contribute to society's development in the context of developing countries. Tea and Irish potatoes were used as instrumental value chains in this study. The two value chains were selected based on their productivity and distribution across different parts of the country (see Figure 3 and Figure 4).

4.2. Sampling process

This research focuses mainly on two levels of analysis, the macro- and meso-levels. The macro-level considers the national level, whereas the meso-level considers the sectoral level (in this case, the agricultural sector). At the macro-level, I examined the ministries and government agencies/boards that are mandated to develop and promote STI and other activities related to R&D management. In addition to these public institutions, other research and development institutions, industry, and the private sector were included in the sample. This macro-level was primarily used to examine the NIS construction process and to identify the driving (and constraint factors) relevant to research and innovation uptake in Rwanda.

At the meso-level, the dynamics in the agricultural sector were explored. The agricultural sector innovation system in Rwanda is relevant to actors who

specifically contribute to the agricultural sector, including the leading institutions in Rwandan agriculture and the middle-level stakeholders. Middle-level stakeholders included research institutions and NGOs that only intervene in the agricultural sector with particular interventions and farmers' cooperatives and related industries. International bodies that are involved in funding or conducting research were considered at both the macro- and meso-level, depending on their areas of intervention. Individual industries were included in the sampling scheme based on the commodities that they worked with, namely, either Irish potatoes or tea. The two commodities have the potential to provide appropriate informative views because they represent both subsistence farming and cash crops (industrial crops). Both crops are considered to be highly productive and have diversified stakeholders. Based on the abundance of these crops, the north-western region of Rwanda was selected to explore interactions at the commodity level, which was considered part of the middle-level stakeholders' interaction.

Interviewees were purposively and systematically selected at both levels based on their positions in their respective institutions. At the policy-making agencies, top-level managers were interviewed, at least one per agency. Based on structures of consulted public agencies, each agency had between two to three top-level managers from which interviewees were selected. At the academic and research institutions included in this study, interviewees were also selected based on their managerial position and research experience. The same as in public agencies, at least one senior manager was selected from two or three available senior managers as per the administrative structures of consulted universities. Regarding the universities included in this study, attention was given to universities that offer courses in agriculture subjects. Consequently, two universities were selected for interviews: one public university (the University of Rwanda) and one private university (the former University of Kibungo). The selection of industry-based interviewees depended on the person's executive level and the person's technical engagement in the factory operations. Factory managers and production managers were interviewed. Regarding the perspectives of farmers, interviewees were selected from farming cooperative committees, at least two members from a committee of six members.

4.3. Data collection

4.3.1. Primary data collection (qualitative interviews)

The interview is the most popular method for qualitative research; it is based on the interactions between the interviewer (researcher) and the interviewee. An interview may consist of a structured discussion that is guided by a series of questions, or an interview may take the form of an open discussion with topics suggested by the researcher. Qualitative information is acquired during the discussion between the interviewer and interviewee and is later transcribed, coded, and analysed systematically to provide knowledge about the topic that was discussed (Potter and Hepburn 2011). The presentation of qualitative information usually includes several key themes that are identified by the researcher using different techniques as described by Ryan and Bernard (2003). The central techniques that are used in this context include scrutiny and processing techniques. Both techniques lead to a more precise selection of themes depending on the study's objective, the skills of the researcher, the type of data collected, and available resources. For the present study, a combination of both was used; I used the scrutiny method for coding interview transcriptions, noting the repetition of keywords, and formulating themes. Existing knowledge in the field was also used in organizing the qualitative information that was obtained from interviews. This consisted of arranging and sorting the information as well as checking the keywords and co-occurrences of words in my interview notes.

For this research project**,** qualitative data was collected in Rwanda to assess how various national frameworks (policy and institutional mainly) are constructed and assess the interactions between stakeholders. Semi-structured interviews were used to acquire information regarding the institutional setting, policy development and implementation processes, collaborations, level of stakeholders' interactions, and their role in the National Innovation System. Interviews were conducted with different categories of stakeholders, including top-level policymakers, research and innovation managers at public institutions and universities/research institutions, senior researchers, private sector/industry actors, and farmers (cooperative). The interviews were conducted in two series, using different interview guides (see Paper II, Paper III and Paper IV).

The first series of interviews was conducted during the period of December 2017 to February 2018, and the second series took place during the period of

December 2018 to January 2019. The two series of interviews followed two different interview guides. During the second round of interviews, the interview guide that was used was specific to the category of the stakeholders who were interviewed. Both rounds of interviews included a total of 44 interviews, with 24 in the first round and 20 in the second round. Figure 5 provides more detail regarding the category of interviewees and how information from each round of interviews contributed to the four individual papers. Each interviewee was provided with a summary introduction to the purpose of the research project and a request for the interviewee's consent. All of the interviewees provide consent, even though some interviewees requested that their anonymity be preserved. During the interviews, notes were taken since many interviewees did not wish to be recorded on tape. Only the name of the hosting organization was recorded in the notes. The interview notes were kept confidential, and only the research team had access to them.

In addition to these interviews, an online survey was conducted as a rapid assessment of the Rwandan research and innovation landscape. A set of generic questions (described in Paper I) was sent to ten top-level managers at the ministries, public agencies, and universities. Seven individuals responded to this questionnaire. The questions focused on identifying enablers for research and innovation uptake, stakeholders' collaboration, synergies in research management and research facilitation, research infrastructure, and research capacity building.

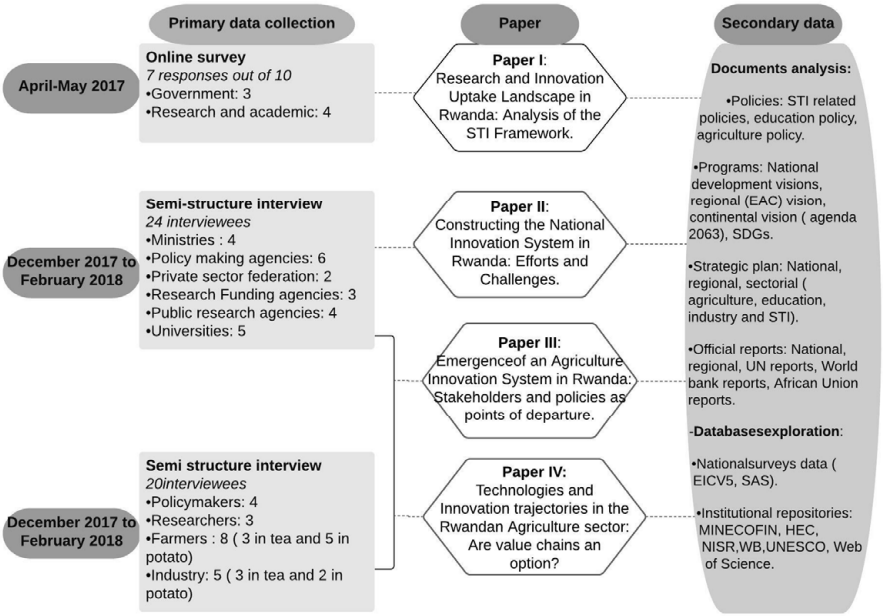

Figure 5: Description of the overall data collection process.

4.4. Positionality and data validity

This research is based on primary data collected through interviews. This data provided insight into the contextual realities relevant to analysing how knowledge uptake for innovation and development in Rwanda is organized. However, as a Rwandan researcher who is passionate about social development and the impact of research on society, it was very important to me that I avoid any bias in my research; for example, by promoting one narrative over another, taking issues for granted, or overlooking (or undermining) them. I have attempted to avoid these biases by ensuring scientific integrity in the design of field research instruments, the selection of respondents, data processing, and my analysis and presentation. Data was collected objectively based on scientifically valid methods and research instruments whose design was informed by the primary analytical framework in this study, namely the NIS (as discussed above).

By adopting the NIS framework in this study, the selection of respondents was determined by the categories of NIS actors and their functions. However,

where some actors were not available, adaptive mechanisms were applied to find other reliable sources of information. This was the case for industry, where the Private Sector Federation and the National Industrial Research Agency were considered key sources of information regarding the expected role of industries in the NIS. Moreover, wherever possible, processing industries were included in the sample. This was the case of the potato value chain and the tea value chain. All of the interviewees were knowledgeable in the subject, as confirmed by their functions in their organizations that positioned them as experts in their fields. According to Bogner, Littig, and Menz (2009), experts are the best source of information for subjects that are broad and encompass a wide range of actors at different levels. Expert views provide meaningful direction for debates on their subject. Experts are a source of information that can be used to answer current questions in ongoing debates and may contribute to future debates. In the case of the Rwandan NIS as an emerging Innovation System, selecting experts from the categories found in the NIS was the best option. This decision was motivated by the complexities in the system and the relatively low level of awareness of innovation processes and knowledge uptake in Rwanda. The information that was collected during the interviews had a high level of validity and relevance to the research questions. The interviewees possessed expertise that was acquired through their experience of their profession and their knowledge in the field.

As a researcher, I tried to maintain the originality of the information that was collected during the interviews by organizing interview notes. These notes were a record of the issues that were discussed as per the interview guide and were cross-checked with the interviewees. Before my analysis of the interview notes, the respondents validated the information that was recorded in the interview notes, where possible. The interviewees have access to the scientific published articles produced during this research project and expressed agreement with how the information was used. The analysis of data was based on the existing framework, tools, and concepts (discussed in the analytical framework) to ensure that the results of the study remain informed by contextual realities but also can be integrated into existing scholarly debates.

4.5. Data organization and analysis

The data was organized in a structured way prior to its analysis. Interview notes were taken during the interviews and were later organized in terms of questions per category of stakeholders. This organization of the data allowed the performance of data comparisons based on three main categories of interviewees. The interview questions were grouped in themes that were based on the study's specific research questions and selected parameters for exploration (see Figure 1). In the data organization process, coded interview notes were grouped in a way that allowed for the identification of commonalities in the interviews' statements in each category of interviewees. The same was done to identify differences in opinions between the stakeholders. This approach also allowed us to group issues and themes by trends, based on the commonalities and differences identified in the interviewees' statements.

During the organization of data into themes, the National Innovation System was referred to as the overarching analytical framework. Based on the NIS framework, components of the system were identified and the associated forms of interaction for components. Themes were classified based on specific research questions in the individual papers included in this thesis. Further details on these themes are provided in the individual papers.

4.6. Methodological limitations

Despite the systematic thinking that structured the data collection and data analysis processes, this study is still faced with several methodological limitations. These limitations are chiefly related to contextual issues, access to information, and methodological choices. They are presented here as a reflection of the different perspectives that can be adopted in exploring the issues studied in this thesis. However, I believe that methodological choices made in this study were adequate to convey confidence in the empirical material collected during the study and the results that address the study's research questions.

In terms of contextual limitations, the NIS framework, as originally framed in the perspective of developed economies, emphasizes the role of the industrial sector as the key end-user of knowledge. In the Rwandan context, as discussed in the empirical setting section, the industrial sector is not yet well developed.

Only a few processing and manufacturing industries are in place in the country. Thus, the low level of representation of industry in the sample. However, there is a national organ that oversees the private sector's interests and visions (industry is included). There is also a public agency in charge of industrial research. These organizations were consulted to ensure that all aspects related to the expected roles of industry and the private sector, in general, were included in the study. In future studies, when the industrial sector is more advanced, we can take improve the present analysis by including complete information on the role of industry in the Rwandan NIS.

In addition to this contextual (structural) limitation, there were issues with accessing and scheduling meetings with the respondents. Most of the respondents were senior managers; they had busy schedules that, to some extent, were beyond their control due to the nature of their work. In many cases, interviews were cancelled or rescheduled. This affected the timing of interviews and the flow of information collection. However, it did not affect the overall expected quality of data. In relation to the seniority of respondents, some respondents were in politically sensitive positions, thus precluding them from commenting on some sensitive policy or government program. In many cases, the respondents refused to be recorded during the interviews. I accommodated this refusal by taking handwritten notes instead, which turned out to be an efficient way of recording the interviews as well. However, this procedure affected the time allocation for data collection because I had to conduct the interviews on my own without any assistance to ensure that the content of the interviews was correctly recorded and interpreted.

Whilst the acquisition of primary data was subject to a number of limiting factors, access to secondary data was also challenging. This was due to inconsistencies in different data sources. The fundamental inconsistencies were found in the statistical data that was recorded in national and international databases. Differences in this data was due to either the methodologies used in data collection or the purpose of their use. Because this thesis focuses on contextual realities, I decided to use national data to explore the relevant policies and strategic actions taken to respond to society's needs. In cases where there were multiple reviews of policies and duplication of reports, I choose to use recent reports or reports from offices that possess a direct mandate for the subject of inquiry (for example, the Rwandan agricultural policy could be preferred over the USAID policy guide on agriculture). This does not entail that other sources of data were discarded entirely; they were used where appropriate. Other means of verification were also used to cross-check the accuracy of the information that was collected, including the

examination of metadata or the making of inquiries at the office in charge of executing a particular policy.

The status of research on NIS and the field of innovation studies, in general, is at a very early stage in Rwanda. There are only a few published academic articles on the topic, and the few consultancy works that exist are more mission-oriented and less reflective on core contextual issues. Instead, they try to fit the international donors' narratives and frames of reference, thereby distorting the contextual reality. This potential source of contextual noise also makes it challenging to choose which issues one should focus on and to establish baselines to construct sound and robust analysis. Under these conditions of limited scholarly knowledge about the Rwandan NIS and the broadness of the NIS framework, it was a challenge to use the NIS as a single framework in my investigation into how knowledge uptake is being organized for enhancing innovation and development in Rwanda. Thus, the choice was made to select supplementary analytical frameworks to capture several specific issues that cannot be otherwise captured by the NIS framework (as discussed in the analytical framework section). This methodological choice was made consciously, knowing that critics of some of the frameworks, including the Value Chain Model, argue that such a model can reflect a linear way of thinking, whilst the thesis advances the idea of interactive learning. To put these supplementary frameworks to good use, I focused on how they have the potential to complement the NIS, given that it fails to engage with specifics of how relationships and interactions are initially established. Both the Value Chain Model and the Triple Helix Model were used to capture issues relevant to the actors' relationships, policy formation, and policy implementation. In doing so, criticism about these frameworks does not impact this thesis's aim since they are not relevant to the scope of the study.

5. Empirical results

This section summarizes the results of this study that were based on interviews and secondary data. The results are organized according to the findings reported in the individual papers included in this thesis. These results address the main research question (see Table 2). In Paper I, I focus on STI policy and institutional frameworks. I present an overview of how policies are formed and implemented and identify a number of challenges and constraints for STI advancement in Rwanda. Paper II provides insight into the construction process of the NIS in Rwanda. In this paper, I discuss the emergence of the 'NIS' concept and how it has been integrated in Rwanda, focusing on interactions between stakeholders. In Paper III, I discuss policy and stakeholder interaction as key pre-conditions for promoting innovation in the Rwandan agricultural sector. Finally, in Paper IV, I discuss how technology and innovation trajectories are organized in the Rwandan agricultural sector by using the value chain approach.

Table 2: Summary of the empirical results of each paper

Title of the paper	Key results
Paper I: Research and Innovation Uptake Landscape in Rwanda: Analysis of the STI Framework	-Major STI policies are in place, but their implementation is constrained. -Major institutions are in place with defined normative functions. - Major factors that constrain R&I uptake in Rwanda are (i) a lack of trust among stakeholders, (ii) a lack of financial capacity, (iii) the low quality of research outputs, and (iv) a weak IP system.
Paper II: Constructing the National Innovation System in Rwanda: Efforts and Challenges	-There is a high degree of political will to support 'NIS', and key stakeholders have understood the concept. - Rwanda has made considerable progress in adopting the 'NIS' concept in the context of the East African Region. -Interactions between stakeholders and STI capacity remain limited. -Policy and institutional coordination remain weak.
Paper III: Emergence of an Agriculture Innovation System in Rwanda: Stakeholders and Policies as Points of Departure.	-Major stakeholders in the Rwandan Agriculture Innovation System are in place and understand their role in promoting innovation in the Rwandan agricultural sector. However, their interactions with each other are weak. -Consultative meetings are the main avenues of interaction. -Policies and policy instruments are supportive of innovation and provide an orientation to initiatives that provide conditions for innovation. - Evidence-based policymaking remains low-level activity, and policies are primarily state-driven and influenced by international development agendas.
Paper IV: Technology and Innovation Trajectories in the Rwandan Agriculture Sector: Are Value Chains an Option?	-Value chains provide a structural organization that can be used to organize innovation and technology transfer initiatives in Rwanda. -Farmers have high expectations for local technologies and innovations, but the importation of technology remains dominant. -Workshops, meetings, consultancies, internships, and farmer-processor contracts are the primary tools that are used in knowledge transfer among value chain actors.

5.1. Policy and institutional frameworks

5.1.1. A brief description of the policy environment in Rwanda

Policies, institutional frameworks, policy networks, and policymaking processes are major components of the policy environment that defines policy success. However, these components are context-dependent and can either accelerate or hamper the development process, depending on how good or bad they are. A level of synergy, coherence, and coordination across policies is important in a policy network if one wishes to achieve positive policy outcomes. However, success also depends on the level of the actors' engagement and the degree of interaction within their networks (Borrás 2011; Chaminade and Lundvall 2019). In the Rwandan context, policies build on the

basic principles set out by the Rwandan constitution, which also set the stage for the aspirations and values of Rwandan society. This policy background is accompanied by long-term visions that are implemented through medium-term and short-term programs and plans. An example is Vision 2020, initiated in 2000 and implemented through the EDPRS I & II as major short-term strategies. Vision 2050 has now been launched in conjunction with the National Transformation Strategy I as a bridging strategy between Vision 2020 and Vision 2050 (MINECOFIN 2012; 2013; 2017; 2020).

The policymaking process is embedded in the government system, which is considered to be decentralized from the organizational point of view. Each policy is approved by the cabinet and is assigned a custodian ministry in charge of the policy development process since many policies affect socio-economic issues (for example, education, agriculture, industry, environment, and healthcare). Policies are implemented by a wide range of actors, including state and non-state actors (for example, NGOs and Community Based Organizations). There exist administrative structures from the national level down to the village level, including the national level, provincial level, district level, sector level, cell level, and village level. These administrative structures are expected to accommodate the flow of policy actions. However, a multilevel network of actors becomes a challenge, to some extent, when policy incoherence and conflicts arise. For example, policy conflicts between agricultural policy and environmental policy may arise (Van Oosten et al. 2018). This is a consequence of the low level of engagement between the various stakeholders and the limited number of avenues for interaction and policy consultation. Official meetings and workshops are the most popular means of consultation. However, they are seen by non-state actors as pre-determined 'consultations' with intended outcomes already decided upon. This circumstance makes it challenging to conduct open debates and welcome new (sometimes controversial) ideas.

Although I note a policy implementation structure that aims for decentralization, several stakeholders I interviewed still perceive the policy-making process as a top-down process and (ultimately) state-driven. Some hold the view that policies are made with the high ambition of integrating with global systems before local issues are dealt with. This view emphasizes the lack of systematic evidence-based policymaking at different levels, including the national level and institutional level (Paper III elaborates on this problem). As pointed out by STI policymakers and researchers, there have been cases of policy failure that can be associated with the way a policy was formed. An example can be seen in education policy instruments that are subject to

repeated changes. Consequently, the education policy is seen by stakeholders as inconsistent and not responsive to the labour market. With this view, bottom-up approaches for policymaking can reduce policy failures and conflicts and promote inclusivity, coherence, and proper coordination.

5.1.2. The STI framework: Policies, funding and human capital

Efforts have been made in establishing STI policies and their instruments to advance the production and use of scientific knowledge for socio-economic development in Rwanda. The initial National Education Sector Policy of 1998 was a point of departure in reviving the Rwandan education sector after the tragedy of the Genocide against the Tutsi in 1994 (UNESCO 2014). This policy paved the way for other policies that followed to take a broad sector approach. In 2003, a new education sector policy was developed. Further considerations were made for developing other specialized subsector policies which were aimed at enhancing the production and use of scientific knowledge (MoESTSR 2003). The National Science, Technology, and Innovation Policy of 2006 is one policy that was developed in order to provide a vision and avenues for STI promotion in Rwanda (Murenzi and Hughes 2006). These efforts in developing policies were accompanied by the development of policy instruments that would ensure their implementation. However, STI professionals and researchers who were interviewed for this study perceived that the implementation of policies was slow due to an overlap in policy goals, a lack of human capacity, a lack of financial means, low levels of collaboration between actors, and the lack of a comprehensive institutional framework for coordination. There is a shared view among STI stakeholders (particularly researchers) that all of these challenges are based on the fact that most policies are developed by international consultants who do not understand the Rwandan context and that these policies do not actively engage policy beneficiaries in the policy development process.

Structures have been established to ensure the coordination of STI activities in Rwanda. These structures facilitate interactions between stakeholders and support the implementation of activities relevant to the overall goal of producing and using scientific knowledge for development. These structures have faced a series of reviews and restructuring to achieve stability and delivery of policy goals (UNESCO 2015). Over an extended period, all of the activities related to STI were overseen by the Ministry of Education (MINEDUC) until 2017, when the National Council for Science and

Technology (NCST) was given the mandate to coordinate national Research, Science, Technology, and Innovation activities.

Several entities are in charge of promoting R&D and STI in specific sectors to support this national coordination body. These include the National Industrial Research Development Agency (NIRDA), the Rwanda Agriculture and Animal Resource Development Board (RAB), the Rwanda Biomedical Centre (RBC), and the Rwanda Standard Board (RSB). All of these public agencies have missions that focus on either research and technology transfer (RAB and RBC), industrial development (NIRDA), and certification and standardization (RSB). Nevertheless, there is a lack of collaboration between these entities. This gap can be observed through the lack of joint initiatives, the lack of policy dialogue platforms, the lack of awareness of available policies, and a lack of resources and capacities directed at collaboration in these agencies.

As for human capital development, the higher education system plays a central role in matching local development needs. This role is part of the Rwandan strategic action plan to make STI a core driver for development. The Rwandan education sector provides ever-increasing opportunities for higher learning institutions to operate in Rwanda, and it stimulates competitiveness amongst graduates in the labour market. This competitiveness is achieved by promoting technical education through polytechnics that can produce suitably qualified human resources for local industries. In addition to this, research centres of excellence have been developed at different universities as a means to enable high-quality research activities that are responsive to society's demands. This initiative was associated with prioritizing efforts for research capacity building, even though the number of qualified and active researchers is still low compared to society's expectations regarding research production. According to a research and development survey of 2015-2016[5] , the most active researchers in the higher education sector were MSc holders (44%), and only 22% of active researchers held a PhD degree (NCST 2020b).

STI funding remains a core element for supporting the production and use of knowledge for socio-economic development. In Rwanda, STI funding has been driven by international funding through collaboration agreements and loans. Examples are the education and research capacity-building initiative under the bilateral collaboration between Sweden and Rwanda through the University of Rwanda since 2002 and the collaboration between the Dutch Government and

5 This are updated data for the most recent R&D survey, compared to the data I used in Paper I that is for the R&D survey covering 2013-2014. Paper I was published before the most recent R&D survey report was published.

Rwanda. In addition to this, loans from the African Development Bank and the World Bank have played an important role in R&D infrastructure development. Besides these valued initiatives, Rwanda has started to build its own internal research funding by establishing the National Research and Innovation Fund. R&D investment has increased from 0.2% of the national GDP in 2014 (reference period 2013-2014) to 0.66% of the national GDP in 2016 (UNESCO 2015; NCST 2020b). The commitment for R&D investment funding was 1% by 2020 and has promised to be 4% by 2050 (Gatare, 2016). The current share of the GDP for R&D seems to be small compared to practices in developed countries where R&D investments have increased. Another core issue is how these ambitious commitments to R&D funding will be achieved, in addition to the donor-led research funding. The involvement of the business sector in research funding is another challenge that needs particular attention and appropriate strategies to deal with it.

5.2. The construction process of the National Innovation System in Rwanda

This thesis explores how knowledge uptake in emerging innovation systems is fostered. This section presents a series of significant historical events concerning the rise of the NIS model in the Rwandan context. I use the empirical findings from the survey to provide insight into the construction process of the NIS in Rwanda. I discuss how the concept has been integrated into the Rwandan STI stakeholders and how interactive relationships between stockholders have increased. I also discuss several obstacles to this process. The construction process was analysed by using an interview survey and a systematic review of policy- and institutional framework documentation. The findings that are presented in Paper II are used in this section to discuss further the emergence and integration process of the NIS concept among stakeholders in both narrow and broader perspectives of NIS. The organization of interactive learning processes among the actors is also discussed by outlining innovation pathways in generic terms and the connections between stakeholders. The status of current research and innovation governance is discussed as I identify potential areas of improvement and ways for creating synergies among NIS actors.

5.2.1. Historical indications of the rise of the NIS model in Rwanda

- *Institutional development*

In Rwanda, as in many other counties, different efforts to establish institutional infrastructures have been made, primarily in the domain of education, STI, and R&D. The setting up of an educational infrastructure, starting with basic education and then later higher education and research institutions, are the initial steps in this process. In the past, these steps were taken by colonial powers who were interested in establishing mechanisms that would build internal capacities for local human resource development. Their aim in doing so was often to promote the colonial power's own agenda. In the beginning, during the early colonial period, institutions were organized at the regional level (Rwanda-Urundi-Zaire), but later towards the end of the colonial period, local institutions were established in Rwanda (UNESCO 2015). The establishment of local institutions signalled the first steps in paving the way for Rwanda's current popular NIS model.

In addition to establishing research and innovation infrastructures, the NIS model requires stable and predictable institutions. In the context of Rwanda, the evolution of the legal framework that governs research, science, technology, and innovation began in the 1960s with laws on IP matters and the ratification of different treaties (for example, UN treaties). The primary legal and policy tools that characterize this process include laws, presidential and ministerial orders, policies, procedures and regulations, and strategies and programs. Remarkable efforts in strengthening the legal and policy framework were observed in the period 2010-2018, with several policies and policy instruments being put in place (UNESCO 2015; Simiyu et al. 2010, NCST 2020a). An explicit policy concerning STI was developed in 2005 and was later accompanied by laws that established the National Council for Science and Technology (Murenzi and Hughes 2006), for example.

The evolutionary process of legal and policy tools in support of STI reflects the increase of interest in the integration of innovation and knowledge as a tool for economic growth and development in general (as illustrated in Figure 6). In the 1980s and early 1990s, the development strategy was mainly focused on self-sufficiency in national food production. However, this strategy did not emphasize the role of scientific knowledge in the process. It was principally built on the use of natural resources by exploiting the available land on a larger scale, using appropriate seeds, and using technologies supplied by international bodies that were collaborating with Rwanda at the time. Only by the early

2000s, with the development of Vision 2020 (MINECOFIN 2012), was the development of endogenous capacity seen as a priority.

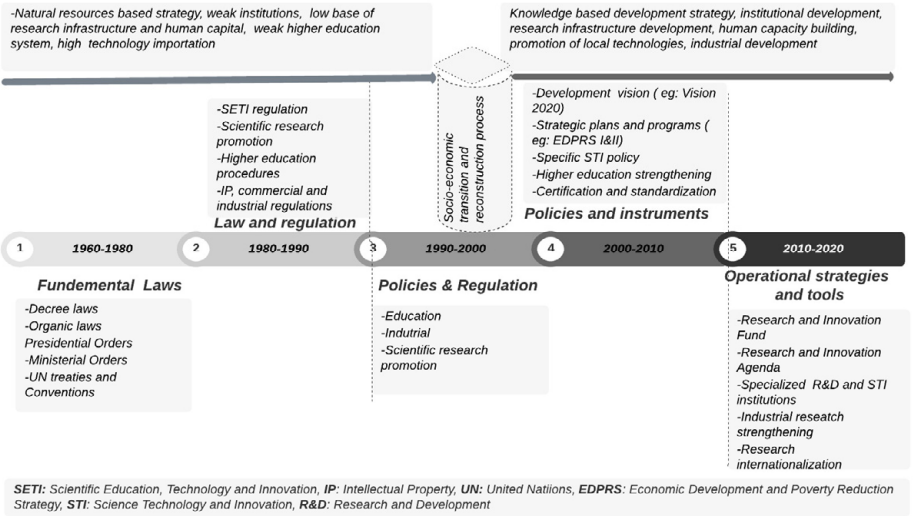

Figure 6: Key indications of the rise of the NIS model in Rwanda.

- *Research capacity development*

In addition to introducing policy and legal frameworks as key elements of institutions that are part of the NIS, the higher education system is another important element of knowledge production and human capital development. The first university was established in Rwanda in 1963. Most of the lecturers were foreigners, including the university management. Prior to that, only two research centres were in existence, and they served a whole region (Rwanda-Urundi[6]-Zaire). Ownership of these two centres was later transferred to Rwanda. The work done at these centres was then focused on addressing problems in Rwandan society only.

The development of the higher education and research system in Rwanda (discussed in the empirical setting section) was associated with strengthening its institutional capacity for research and innovation. This was achieved by establishing university research centres and laboratories conducive to scientific

[6] Now known as Burundi.

research advancement. Research laboratories that can ensure high-quality analysis were established in different places like universities and publicly-run R&D institutions. Recently, centres of excellence have been popular in building specialized research capacities in the academic system. In addition to laboratories, research training programs for PhD candidates have been established. This move was prompted by a desire to phase out the tradition of sending researchers for studies abroad; a strategy for human capacity building that has been used since the 1960s. Training researchers locally is part of building an endogenous capacity that can be responsive to local needs but also holds the potential to produce internationally relevant research.

In terms of scientific output, the number of scientific publications produced by Rwandan researchers has increased over time, as well as the quality of these publications (from zero to 3156 peer-reviewed scientific publications by researchers affiliated to Rwandan institutions from 1960 to 2020, see Figure 7) (Web of Science 2020). The same increase is observed with respect to the number of researchers in different disciplines, thereby giving one explanation for the increase in scientific publications. International collaborations also have been strengthened, as seen in authorship and grant collaboration patterns (Figure 8). These efforts enhance the internationalization of locally produced knowledge. Capacities in organizing conferences have increased as well as the related facilities for the hosting of conferences and scientific meetings (for example, the Kigali Convention Centre and the Kigali Culture and Exhibition Village (owned by the University of Rwanda)). These are key avenues whereby interactive learning processes can be initiated for sharing newly produced knowledge and experience. However, more can be done. We should move from the (mere) dissemination of research outputs to their actual use in solving society's problems. This would involve robust collaborative partnerships between industry and universities, particularly in the areas of technology development and increasing production and competitiveness.

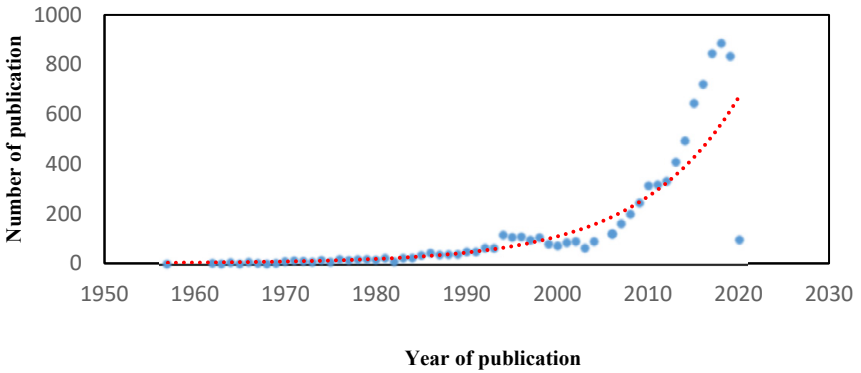

Figure 7: The increase in number of scientific publications from 1960 to 2020.
Source: Web of Science 2020

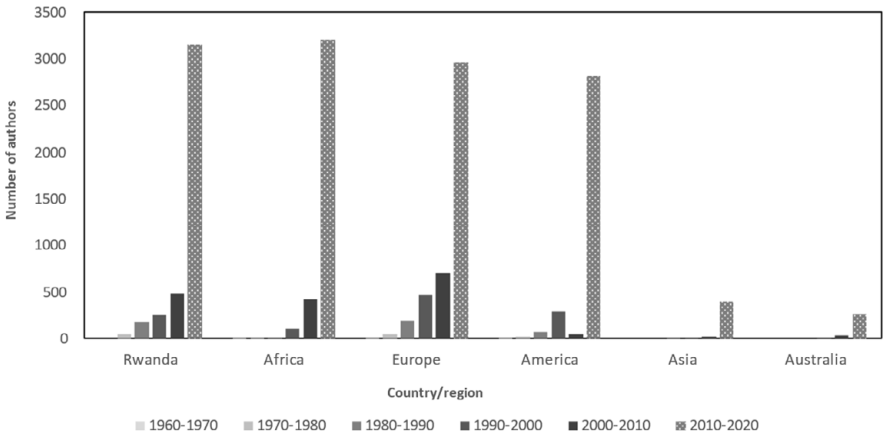

Figure 8: Number of authorship affiliations/collaborations from 1960 to 2020.
Source: Web of Science 2020

5.2.2. The Rwandan National Innovation System

A survey of STI personnel in Rwanda (presented in Paper II) reveals that not every stakeholder uniformly understands the 'NIS' concept. The generally low level of awareness of the concept among stakeholders makes it more difficult for actors in the innovation system to work in harmony with each other. Without a clear understanding of the inner workings of the innovation system,

the identification and alignment of inter- and intra-institutional responsibilities become haphazard at best (Chaminade et al. 2018; Fagerberg et al. 2018). Academic and research institutions in Rwanda appear to understand the concept fairly well, whereas private and government institutions have a relatively low level of understanding of the concept. This low level of understanding of the concept in emerging innovation systems does not favour the establishment of efficient relations and institutions that can foster innovation and knowledge for economic growth.

Nevertheless, effort has been made in establishing institutions and organizations that can promote higher education and research, but the interactions between institutions that are emerging, and the rest of the society remain challenging. The respondents in this study recognized that a robust education system could help in building the Rwandan NIS since a functioning education system can serve as an important source of qualified graduates who, in turn, can serve in the business sector and in society at large, thereby increasing its absorptive capacity. In the interviews, good performance in problem-based research was highlighted as a key driver for constructing a NIS, but the Rwandan research environment currently shows a low level of interaction between researchers and research end-users. This causes the research that is being conducted unresponsive to the demands of society. Consequently, we require strategic and systemic mechanisms to facilitate knowledge transfer and knowledge use processes. As suggested in the Triple Helix Model, the function of organizational control can be exploited to address this issue. This is, in principle, a primary role of the government as per the predefined normative functions of government actors. However, in an emerging innovation system, blended modes of intervention can be of use. This involves a high level of engagement and ownership of all of the actors in the system at different levels and capacities. In this case, joint initiatives can be one option that can be explored to consolidate efforts and work towards a shared interest, namely, the use of knowledge for national socio-economic development.

At the current stage of the construction process, from a narrow perspective, we note that there is a low level of interactions in STI organization and R&D performance. A narrow perspective focuses on the organization of the STI and R&D performance since it is crucial to NIS maturity and performance (Cassiolato et al. 2006). As a result of the low level of interactions, the current status of the development process of the Rwandan NIS seems to be at the early stage, although its future is promising based on the observed commitment and trends in activities aimed at establishing an operational NIS. Taking a broader

perspective that includes an overview of the overall operational environment, we observe that it seems to be more developed because there is a high degree of political will expressed in the relevant policy documents and leadership commitments. The high levels of interest expressed by society at large indicates that there exists a good level of social and cultural acceptance of innovations. In some developing countries, this is sometimes a challenge in the NIS construction process. Again, from a broader perspective, achieving adequate levels of coordination and absorptive capacity are also among the major challenges in the NIS construction process.

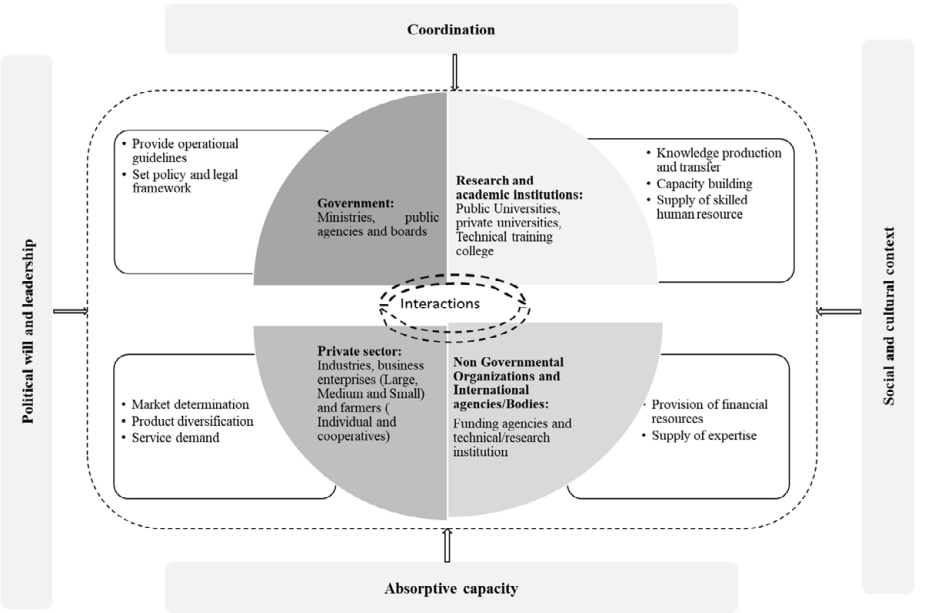

Figure 9: General layout of the Rwandan NIS.
Source: Authors' compilation of data collected from interviews, 2018

5.2.3. Systemic interactions: Innovation pathways and stakeholders' linkage

The process of *innovation dissemination* remains unclear to many stakeholders in Rwandan institutions. It is perceived as challenging to understand, even more challenging to realize in practice. In this context, the term *dissemination* entails bringing innovation to end-users, either in the form of a commercial

undertaking or as a social innovation that is transferred directly to the end-users, for example, in the form of improved agricultural farming techniques. Only a few representatives of the institutions included in this study reported taking substantial steps in disseminating innovations. The principal reasons why there is such a low rate of innovation dissemination include (i) a lack of a clear dissemination framework, (ii) a lack of coordination at the national level and within institutions, (iii) a lack of flexible systems that allow dynamism among stakeholders, (iv) a lack of skills in profiling which innovations should be disseminated, (v) a lack of financial means, and (vi) a lack of a supportive and receptive mindset for innovation in end-users. In addition to these major reasons, other causes for the low levels of innovation dissemination include poor information sharing, a lack of knowledge commercialization strategies, and poor skills in intellectual property management, as reported by the interviewees. In sum, all of the above were described as factors that constitute obstacles to the effective dissemination of innovation.

A lower level of collaboration between local institutions was observed compared to the levels of collaboration demonstrated by international and regional institutions. Collaborations between public institutions are few and far between, and most of the actors claim this to be the root cause of the low performance of the entire system because, in many cases, this results in unnecessary and wasteful duplication of work. Collaboration between universities and local industries/the private sector was judged to be almost non-existent. Even in cases where a government incentive has initiated collaborations, they did not fully materialize and did not result in any positive impact or sustained initiative contributing to innovation development.

Research and innovation policy and governance frameworks in Rwanda are perceived by stakeholders as relatively supportive of research and innovation development, albeit with limited enabling capacity since there are currently no recognizable incentive schemes for innovators and researchers. Policies for STI are perceived as well formulated as they are considered to be aligned with the government agenda and development plans. However, this does not exclude the observed duplications and overlaps in policies, resulting in low rates of implementation and a waste of resources.

Despite the effort devoted to implementing new structures for research governance, innovation management is still lagging behind and is but weakly institutionalized. During this study, there was no organization in Rwanda with a specific innovation policy remit, and only a few public organizations had offices that focus on innovation matters; those within the academic and research sphere. Examples are the University of Rwanda and the National

Industrial Research Development Agency. In most other settings, research and innovation are managed under research units, and research strategies cover innovation matters with respect to policies.

5.3. Creating the preconditions for emerging innovation systems: The case of agricultural sector in Rwanda

The Rwandan National Innovation System is currently under construction, with considerable effort being made to promote the use of scientific knowledge for social development. The innovation system recognises that it is essential that conditions be improved to innovate in different sectors of the economy if positive results are to be realized. Agriculture is a socio-economic sector with the potentials for innovation development in the Rwanda context, as acknowledged in the interviews reported in Paper II and various policy documents. As discussed in Paper I and Paper II, innovation development requires the support of the policy environment and proper alignment of innovation activities and other economic structures. This can be achieved through interactions between stakeholders in the sector. In this section, based on the findings in Paper III, I discuss the role of stakeholders and policies as key preconditions for building an agriculture innovation system, thereby enhancing our understanding of the conditions for innovation in Rwandan agriculture.

5.3.1. Stakeholders and their roles in supporting innovation

The role of stakeholders in innovation processes is important across different dimensions. However, their impact depends on how they interact with each other and how they complement each other. Stakeholders in the Rwandan agricultural sector fall into the following main groups: farmers, government, non-governmental organizations, the private sector, and knowledge institutions. The farmers' group is primarily composed of farmers' federations and cooperatives as well as individual farmers, including small-scale farmers and large-scale farmers. The sub-category of small-scale farmers consists of farmers with less than 0.7ha of farmland, whereas large-scale farmers farm from 1ha of land and above (Rwirahira 2009; Ayalew Ali et al. 2014). Non-Governmental Organizations comprise both local and international

organizations. They also include UN agencies and regional/trans-boundary bodies that are directly or indirectly engaged in the agricultural sector. Line ministries, aligned agencies, and local entities compose the government category, whereas the private sector category is composed of agro-dealers and agribusiness entrepreneurs, including industry. Research and training institutions (i.e., higher education) are found in the knowledge institution group.

These main groups of stakeholders have a wide range of roles and functions with respect to the development of innovation in the agricultural sector in Rwanda. The government provides an operational environment through planning and policymaking. Knowledge institutions conduct research and technology transfer to provide needed skills and technology to address problems in the sector. The research dissemination and technology transfer roles are – ideally – accomplished in an interactive way. This involves a knowledge institution as the technology provider and public agencies and NGOs as facilitators. Farmers are thus classed as technology end-users. Innovation propensity is expected to increase through these interactions and mutual learning among the stakeholders. Financing and commercialization roles in the private sector translate these efforts into economic significance.

Interactions between stakeholders that aim to perform the above-mentioned roles and functions remain limited, as highlighted by stakeholders interviewed for this study. However, they recognize the value of work done to enhance interaction through consultative meetings and workshops. In many cases, these meetings and workshops are organized by government organizations, universities, and NGOs. These measures are not seen as satisfactory, especially when compared to the high expectations made with respect to research, technology, and innovation as the main drivers for the transformation of the agricultural sector in Rwanda. This low level of satisfaction regarding these efforts is merely due to the lack of effective and efficient mechanisms for said interactions. Tools and frameworks, such as innovation platforms, Farmers Field Schools (FFS), annual national agriculture shows, professional platforms, and ICT for Agriculture, have been initiated to overcome challenges to collaboration for research, innovation, and technology transfer. These tools are expected to offer opportunities for interaction, raise awareness about the available knowledge and technologies, and provide information about how they can be accessed and used. However, these mechanisms need to be operationalized cautiously with proper leadership and equality. Issues of inequality (financial and social inequality) and power imbalances have been identified as limiting factors in places where these mechanisms have been

previously applied (Adam et al. 2018). Thus, on-ground facilitation efforts are key for the use of these mechanisms if they are to enhance interaction and complementarities among actors.

5.3.2. Role of policies and policy instruments in supporting innovation in the Rwandan agricultural sector

The impact of policies and policy instruments is principally determined by policy drivers and how policies are made. Policy actions are key to indicating what needs to be done and in identifying strategies to achieve policy goals. In the context of the Rwandan agricultural sector, several policies and policy instruments in support of innovation for agricultural sector development and national socio-economic development have been introduced. Such policies and instruments provide key priorities, indications of major policy actions, and information about how they can be implemented to increase innovation propensity in the Rwandan agriculture system. Chief among them is the National Agriculture Policy that builds on long-term visions such as Vision 2020. Policy instruments, including strategic plans, regulatory frameworks, quality and standard assurance mechanisms, and industrial and export strategies have been developed to support key policies that aim at advancing the development of the agricultural sector and its impact on socio-economic development in Rwanda.

The policies and policy instruments that are currently in place provide the orientation and conditions for innovation in the Rwandan agricultural sector. Major policy goals and actions emphasize enhancing research and technology transfer efforts as a mechanism to address identified issues. Research programs and infrastructures have been developed for addressing issues of seed improvement, disease and pest control, and improved genetic resources (in both animals and crops). These areas are viewed as major problems in the local conditions. Infrastructure, including gene banks, seed centres, and germplasm centres have been established as a means to facilitate research and the advancement of agricultural technologies. As a means for community outreach and technology dissemination, technical tools for helping farmers have been developed, and platforms for interaction and capacity building have also been initiated. The Farmer's Field School (FFS) is a policy instrument that has been initiated to facilitate technology transfer between researchers and farmers (Gahakwa et al. 2014). Policies have also indicated an interest in innovation platforms, Master Training, and Farmer Promoters as facilitating tools for technology transfer and innovation development (MINAGRI 2018).

Although several policies and policy instruments are in place, they need to be actually implemented if they are to have any impact on innovation development. The process of developing and implementing policies must ensure coherence in terms of policy mission, actions, and resource endowment. Respondents from the private sector and NGOs included in this study reported that resource allocation by the government for policy implementation remains low, particularly in terms of the budget that is allocated to support the development of agricultural technologies and technology transfer activities. In addition to limited budgetary resources, there is a lack of qualified human resources who can support activities that are relevant to policy orientations and actions. Based on the complexity of the agricultural sector in Rwanda, there is a high risk for policy conflicts and policy failures. This is due to the wide range of stakeholders, complex policy problems, and institutional weaknesses. Note that these conditions would even hamper the development of an efficient agriculture innovation system. Thus, in addition to policies and policy instruments that indicate what should be done, an enabling organizational framework needs to be put in place to allow resource circulation and their efficient use. This can be achieved if stakeholders engage in joint activities with mutual interest. In doing so, systemic thinking and systemic actions can be developed and lead to a mature innovation system.

5.4. The value chain as a policy instrument to shape technology and innovation trajectories in the Rwandan agricultural sector

As indicated by the main research question in this thesis, the facilitation of knowledge use for socio-economic development may take a multitude of pathways and might follow different trajectories depending on the type of knowledge that is being applied as well as the context and the expected developmental outcomes. I argue that different tools can be used to provide organizational structures for knowledge dissemination and knowledge use. Referring to the findings in Paper IV, this section provides insight into how agriculture value chains can be used as a point of departure for the setting of trajectories for technology and innovation in the agricultural sector. I consider value chain activities as fundamental structures for the integration of innovation in the value chain. In the context of this thesis, agricultural commodity value chains are considered as part of the policy instruments that

have been adopted to increase profitability in Rwandan agriculture. Based on this observation, they are assumed also to have the potential to be instrumental in promoting innovation since there is a high interest in technology and innovation to improve the agricultural sector in Rwanda. I selected two key value chains (the Irish potato and tea crops) to analyse (i) ways of mainstreaming technology and innovation in these value chains' activities and (ii) how value chain actors' interactions are organized to facilitate the integration of innovation at different stages in the value chain.

5.4.1. Entry points for technology and innovation: Value chain activities and actors' interactions

Agriculture value chains in Rwanda are generally perceived to be short and less diversified in terms of the activities and products that are associated with them. However, they are important in the coordination of key activities, particularly with respect to specific commodities (MINAGRI 2018). Both subsistence crops and cash crops (industrial crops) in Rwanda have adopted the value chain approach to enhance their competitiveness in the market. Based on the value chain analysis approach suggested by Porter (1985), a value chain consists of two main categories of activity: (i) primary activities and (ii) support activities. In the selected value chains, primary activities include 'inbound and outbound logistics, operations, marketing and sales as well as service'. Inbound logistics include production activities, such as land preparation, farm maintenance, crop protection, and other associated activities. Outbound logistics activities include harvest collection, processing, packaging, and delivery. Marketing and sales activities include pricing, commercialization (including export), communication-promotion, and product diversification based on the market demand. Services are mainly agro-input delivery, extension services, and training for stakeholders. Operations include standardization and certification, branding, and record keeping.

All of these primary activities are supported by 'support activities'. They include 'infrastructure development, human resource development, public procurement and technology and innovation development'. Even though they are classified as support activities in the value chain, agricultural technology development and innovation are key activities and are relevant to all the other activities in the value chain, including primary activities and support activities. The value chain structure allows stakeholders to perform innovation activities at different stages of the value chain, depending on the value that needs to be added and profit maximization. However, doing so requires a clear

understanding and a separation of duties between actors and means if one is to develop synergies and complementarities.

Several actors are involved in performing several of these activities in different capacities. However, it is imperative to develop synergies if one is to maximize profit in the value chain. The main actors in the two value chains that are analysed in this study include (A) farmers who are actively involved in inbound logistics (farm activities mainly) and (B) processors who are engaged in outbound logistics (collection of harvest and post-harvest handling and processing). Government agencies and NGOs are primarily involved in operations and services. Universities are expected to act as key players in technology and innovation development. Infrastructure development remains the government's responsibility, along with investors. However, as pointed out by the respondents in this study, there are no remarkable synergies between actors in the Rwandan agricultural sector. It remains a challenge to realize complementarities and maximize resource use in these value chains. This also negatively affects potential value addition from innovation and technology. The lack of synergies is chiefly due to the low level of interactions between actors (the government, universities, and industry). The principal causes for the low level of interaction that was mentioned in the interviews are (i) a lack of avenues and frameworks for interaction, (ii) mismatches in interest, (iii) policy conflicts, and (iv) a lack of trust.

From an innovation systems perspective, the above-mentioned causes reflect institutional weaknesses. Notwithstanding this, efficient institutions are the fundamental elements of a mature innovation system. Based on the potential of the value chain regarding issues related to governance and coordination, value chains can be used to enhance the harmonization of interest, policy coherence, and the building of trust. This can be done by supporting existing community-based organizations, such as cooperatives, as avenues for interaction for farmers. This can serve as an entry point for farmers since they are a key group of actors who are involved in many activities of the value chain. In fact, they have a primary role in the adoption of technology and innovation, particularly in primary activities.

5.4.2. Dissemination and use of knowledge through value chain interactions

There is a high expectation that innovation and technology will transform the Rwandan agricultural sector from a model of subsistence agriculture to an agricultural model that is market-oriented. This circumstance has prompted

interest in disseminating and using knowledge to produce innovative solutions to complex problems in the sector. The majority of the stakeholders who were interviewed for this study expected to acquire the necessary knowledge (for example, technical know-how) from research conducted at universities and research institutions. Others stated that they rely on technology being imported to the country. All of the stakeholders acknowledged the importance of combining indigenous knowledge with other types of knowledge, for example, scientific knowledge produced by local researchers *and* imported technologies.

The fact that many of the interviewees considered research-based knowledge as a priority (chiefly by industries and policymakers) can be used to explain why it is necessary to design fit-for-purpose interventions that address real problems in the sector whilst taking into account the Rwandan context and the capacity of actors in this context. The contextual understanding that these actors possess is seen as a point of departure for innovation development in the Rwandan agricultural sector. Even though research-based knowledge is viewed as necessary, it is claimed that current research efforts pay more attention to basic knowledge instead of applied and technological knowledge that responds to farmers' problems. This highlights the value of practical and transferable knowledge, so that end users can quickly adopt it and use it to address the challenges that the sector faces. Despite the high esteem that is awarded to research as a key source of needed knowledge, there is also a perspective that argues that research capacity and research outputs remain limited in their scope. In addition to this somewhat dire picture, we note that the dissemination of the available limited research outputs remains challenging and difficult to establish. Among the underlying reasons for the weak dissemination and uptake of the available research outputs are the limited absorptive capacity of end-users and a lack of appropriate tools and structures to overcome that absorptive capacity barrier.

Given my analysis of value chain activities and actors, I note that knowledge sharing activities are primarily performed with regards to production activities. In the Irish potato value chain, farmers have been interacting with NGOs for training on best farming practices and harvest handling. Technology transfer activities between universities and farmers have been conducted to address potato seed problems and soil conservation. There is an emerging interaction between processors and farmers for using post-harvest handling technologies in order to ensure the preservation of the quality of the raw materials to be used by processors. Consultancies and student internships were major forms of knowledge-sharing between universities and processors for the tea value chain. However, the farmers received guidelines about technology adoption and

technology application from the tea factories (processors) and the national agency in charge of agricultural exports. In both value chains, workshops and meetings are the main avenues of interaction where farmers and other actors in the relevant value chain are brought together. For the tea value chain, a specialized platform for tea professionals has been initiated so that they can engage in peer-to-peer consultation for technological issues that they might experience in the value chain.

6. Discussion and future research perspectives

This thesis consists of four papers, each of which includes a detailed discussion section. The present section briefly discusses the key aspects of NIS building, institutional relations, policymaking, and the organization of knowledge uptake. The discussion focuses on key empirical results in relation to these aspects and provides several suggestions for areas that can be explored for further study. My remarks on policy implications and recommendations are presented separately since this section focuses on future research perspectives. The suggestions provided here are not exhaustive, but they are points of reflection that can be inspirational for the scholarly community that is interested in the issues covered in this thesis.

As mentioned in the introduction, the concept of 'NIS' has been suggested as a potential framework that can be exploited to understand how knowledge contributes to economic growth and social development. It is noted, however, that this concept has evolved differently in different parts of the world. Developed countries enjoy more advanced and efficient innovation systems, whereas developing countries are still struggling to build their innovation systems. The work that is put into building an innovation system in a developing country echoes deliberate efforts in policy learning. However, the way this learning takes place is determined by the context. The results of this study show that the adoption of the 'NIS' concept should be done carefully and should take into account the prevailing economic structures, institutional capacity, and resource endowment as key contextual aspects. Moreover, a proper understanding of the 'NIS' concept and its integration into political and social systems is a key precondition for building an effective national innovation system.

Lundvall (1998), Muchie, Lundvall, and Gammeltoft (2001), and Alkemade, Kleinschmidt, and Hekkert (2007) emphasize the point that the development of innovation systems responds to the conditions of where they emerge and, consequently, there is no 'one size fits all' for different countries and contexts.

The building of an innovation system should be context-specific. However, the main principles, components, and processes of innovation systems should be used as the baseline in the construction process. This baseline should include the actors' nature, capacity, modes of learning, and resource availability and allocation. The Rwandan NIS is subject to weak relationships, resource scarcity, and limited capacities. These features in the construction of a functional NIS remain among the key challenges to organizing the efficient use of knowledge for innovation and development in Rwanda. To address these challenges, a thorough analysis of (i) the specific tools and instruments that can be used to build relationships and (ii) proper resource mobilization and allocation is of capital importance.

As the results show, in Rwanda, effective policymaking and policy implementation remain challenging. However, enabling policies are considered key preconditions for innovation. Despite the lack of specificities in the NIS framework, other supplementary tools were used in my analysis to examine Rwandan policymaking and how it can contribute to the advancement of innovation in Rwanda, specifically in the agricultural sector. Results show that policymaking in Rwanda is still based on policy learning and policy transfer (discussed in Paper III). Evidence-based policymaking has not yet been achieved. This causes innovation policies and associated public policies to be less responsive to society's demands, a condition that ultimately does not favour innovation development. These problems with policymaking can also be associated with the low level of interactions between stakeholders. A combination of less responsive policies and a low level of interactions between stakeholders creates an environment that hampers the construction of a functional innovation system.

As suggested by Borrás and Laatsit (2019), Chaminade and Lundvall (2019), and Arnold (2004), the conditions above call for the implementation of robust coordination mechanisms and a high level of engagement and collaboration between actors. I argue that this can be achieved by creating and enhancing avenues of interaction and policy incentives for collaboration between actors. Since the NIS is context-specific, no single solution will facilitate this. However, further research can explore different options on how efficient interaction between stakeholders can be established so as to increase the stakeholders' degree of engagement and collaboration. Moreover, I also claim that a thorough examination of efficient policymaking mechanisms (with an emphasis on evidence-based policymaking) would reduce policy failures and enable the implementation of policies that support innovation development. This claim can be explored from a perspective of evidence acquisition and use

and strategies for policy implementation and the creation of feedback channels between actors.

In addition to the above-mentioned institutional weaknesses (in terms of policymaking and stakeholders' relations in Rwanda's NIS), several capability problems make the building of the NIS and the organization of knowledge uptake a challenging task. As highlighted by Teece, Pisano, and Shuen (2009) and Cohen and Levinthal (1990), dynamic capability and the absorptive capacity of actors are key factors for innovation competency. Thus, the building of an NIS should take these factors into account and capitalize on them. The Rwandan context shows that there is still limited absorptive capacity, mainly in terms of financial and human resources. There is a low level of R&D investment, a lack of qualified researchers, and a limited critical mass of educated communities for technology absorption. This is particularly true in the agricultural sector. I suggest that these factors are critical challenges that should be explored at different levels and from different perspectives. However, the most pressing issue is our need to understand how education and research systems respond to society's demands and whether these systems can be improved upon so as to respond to these demands.

In principle, the role of education (primarily provided by universities) and research institutions is expected to be achieved when the universities' mission and society's problems are harmonized with each other (Benner, Malmberg, and Schwaag Serger 2021). This can be accomplished by collaboration between the universities and other actors in the NIS. Collaborations can be organized via teaching and research activities. Modes of teaching that allow for interactions between students and the labour market (including industries and the private sector in general) are recommended since they can enhance the students' exposure to industry and produce graduates that meet the labour market's demands. Furthermore, I claim that participatory research is one of the best options to choose from if one wishes to produce more responsive and relevant research outputs. Unfortunately, as per the results of this study, the current situation in Rwanda shows that universities are still limited in terms of their ability to address society's core problems (for example, a lack of industrial technologies and a suitably qualified labour force). Thus, the role of Rwandan universities and research institutions in the development process remains somewhat under-appreciated.

Future research in this area should examine how the contribution that is made by Rwandan universities to the socio-economic development of the country can be improved upon, particularly with regard to the development of the industrial sector. The Triple Helix Model can be a potential framework to

explore the relationship between universities and industry. Etzkowitz (2013) and Arocena, Göransson, and Sutz (2015) propose the concepts of 'entrepreneurial university' and 'developmental university' to understand the role that universities play in the development of society. These concepts emphasize the third mission of universities, which is 'technology transfer' and 'society engagement'. They argue that if universities can accomplish their third mission, then they can be drivers for sustainable and inclusive development. They suggest different options for how universities can be positioned within the dynamics of social development dynamics in a manner that transcends their teaching role. These concepts can also be exploited in the context of Rwanda, considering how universities operate, how they define their missions, and how these missions are accomplished. This approach can be the best way to unpack the role that knowledge institutions perform in the NIS framework. At present, the NIS framework only prescribes activities and actions of universities as knowledge institutions without providing clear guidance on how these activities and actions can be performed.

Concerning stakeholders' interactions, resource endowment, and knowledge transfer and use, we realize that value chains can be used to establish pathways for interactions between actors for technology/knowledge transfer and the coordination of the efficient use of resources in the agricultural sector. Lema, Rabellotti, and Gehl Sampath (2018), Jurowetzki, Lema, and Lundvall (2018), Fagerberg, Lundvall, and Srholec (2018), and Janssen and Swinnen (2019) argue that the co-evolution of value chains and innovation systems can enhance the use of knowledge for economic growth. Particularly in developing countries with weak institutions and relations, this can establish trajectories for innovation and improve the sustainability of innovation systems. In the present study, the results show that value chain actors in the two value chains that were studied are in place, but the level of their interactions with each other with regard to knowledge production, transfer, and use remain low due to a lack of avenues for interaction, a lack of harmonization of interest, policy conflicts, and a lack of trust. However, existing initiatives show that value chains can be enhanced and contribute to building an efficient agricultural innovation system in Rwanda. Nevertheless, this suggestion needs to be explored from different perspectives, particularly with respect to mechanisms that can enhance synergies between actors and improve value chain governance.

7. Conclusion

This thesis has explored how efforts to foster knowledge uptake and interactive learning for innovation and development are organized in emerging innovation systems. I have analysed how policies and institutional frameworks have been (and continue to be) established as part of building a national innovation system. I have used Rwanda as a case study in my assessment of how efforts in building the NIS and associated policy initiatives enable interaction between actors in the production, transfer, and use of knowledge, which aims to provide innovative solutions to society's problems. By using the agricultural sector as a case, I have analysed the role of stakeholders in building the Rwandan agricultural innovation system, and I have examined how policies contribute to advancing innovation in the Rwandan agricultural sector. Commodity value chains were explored as a potential policy instrument that can be used to organize technology and innovation trajectories in the agricultural sector. During my analysis of value chain activities and actors' interactions, I examined several knowledge transfer mechanisms in the agricultural sector. This was done to understand how technology and innovation activities can be organized and performed to develop the agricultural sector.

Referring to several perspectives that can be found in the scholarly literature on this topic, this thesis argues that the adoption of the 'NIS' concept in developing countries should take into account the peculiarities of developing countries, especially with regard to issues related to institutions, research infrastructure, human capital, industrial development, and relationships between and within organizations, capacity building, and the financing of innovation. All of these issues are critical basic requirements to successfully building an innovation system. However, these requirements cannot all instantly be satisfied. They require the implementation of a progressive development process that involves considerable effort in building internal capacities and capabilities. These capabilities are connected to the level of economic development, resources endowment, market systems, and the overall political environment.

Empirical findings show relatively good progress in the adoption of the 'NIS' concept, with critical elements in place. Rwanda has put in place key organizations, policies, and infrastructure, and capacity-building efforts have been made. However, institutions are still weak and even though they are a key element of mature innovation systems. Present institutional weaknesses in Rwanda that need to be dealt with include policy overlaps, policy conflicts, a lack of research-policy debate avenues, a lack of trust between actors, a weak coordination framework between organizations, and a lack of awareness of policies, rules, regulations, and laws for promoting STI. All of these issues hamper establishing interactive relationships between actors. But note that these relationships are fundamental to learning and experience-sharing. Under these circumstances, the production, transfer, and use of knowledge for development remain challenging. One option to overcome this challenging situation is to create networks and platforms that will stimulate interactions between knowledge producers and knowledge users. This can be done either through funding schemes, establishing incubation centres, and providing policy instruments that offer incentives for industries to engage in R&D activities. Incentives can take the form of tax exemptions for knowledge commercialization activities, subsidy schemes, and market protection, where possible.

Although building and sustaining innovation systems is crucial to the process of producing, transferring, and using knowledge for social development, enabling conditions for innovation must be first put in place to provide responsive, innovative solutions to complex developmental problems. Policies, policy instruments, and stakeholders' interactions are major factors for creating conditions for innovation and building effective innovation systems at different levels. However, the impact of policies and policy instruments depend on how they are designed and implemented, whereas for stakeholders, it depends on their roles and functions (and how they perform them). Complementarities and synergies between actors are of capital importance, although they are difficult to achieve in the Rwandan context because of the above-mentioned institutional weaknesses. In this context, policy-making processes and policy implementation should be improved. The empirical results of this study show that bottom-up and evidence-based policymaking are the best options to ensure that policies and policy instruments capture the realities of society and address community problems. Enhanced interaction between universities and the government is one way of ensuring the acquisition and use of research-based evidence for policymaking. Whereas close cooperation between government and Community Based Organizations, such as cooperatives, can be a way to capture pertinent policy problems in the

community. All these can be facilitated through the Triple Helix Model if all of its functions are properly understood and operationalized.

The analysis of agricultural commodity value chains (tea and Irish potatoes) revealed that the structure of value chains (in terms of activities and the way they are implemented) provides a potentially fruitful pathway for technology and innovation trajectories. Once value chains are upgraded, innovation activities can be performed, and learning can take place among value chain actors. Knowledge transfer and mutual learning can also take place via consultancies, student internships, professional platforms, study tours, and training. However, all of these activities require a 'harmonization of interests' among actors and a match between knowledge supply and knowledge demand. Farmers' cooperatives are the best entry points to organize knowledge transfer and mutual learning activities since they are the primary and largest category of end-user of agricultural technology in Rwanda. Furthermore, these farmers possess traditional knowledge (and field experience) that is beneficial to researchers. From examining the two value chains, I note that value chains can be of use in organizing technologies and innovation trajectories in the Rwandan agricultural sector. They can thus serve as a point of departure for building effective agricultural innovation systems. This observation aligns with the ongoing debate about the co-evolution of value chain innovation systems in developing countries.

To this end, I conclude that progress has been made in adopting the 'NIS' concept in Rwanda and that a NIS can serve as a good framework for the use of knowledge for innovation and development. However, this can only take place if institutional relationships are strengthened. This can be achieved through coherent and responsive policies, smooth stakeholders' interactions, efficient resource mobilization and allocation, and infrastructure development. Developing countries that are similar to Rwanda can learn from Rwanda about its potentials with respect to the broader perspective of the National Innovation System, particularly concerning the political will to support innovation and society's motivation to adopt new technologies and innovation.

8. Recommendations and policy implications

The NIS is a framework that has the potential to organize the facilitation of the production and use of knowledge for innovation and development. Based on the progress made in Rwanda, there are several implications from a policy perspective that need to be taken into account if one's goal is to sustain the Rwandan innovation system. I thus make the following recommendations and comment on a number of policy implications:

a) Policymaking and policy implementation are two challenges that affect the facilitation of knowledge uptake in Rwanda. Thus, there is a need for institutional capacity building in terms of policymaking and implementation. This implies the need for policy instruments that (i) stimulate public dialogue for innovation policies and (ii) create channels for acquiring evidence either from researchers or the community in general. These channels can be established by re-organizing or enhancing existing current structures. The creation of professional platforms and regular consultation forums, and the active engagement of stakeholders are two key policy actions that can be explored to build and enhance levels of interaction between policymakers, researchers, and policy implementers.

b) The empirical findings that are reported in this thesis show that research funding remains a significant challenge to knowledge production in Rwanda. This circumstance thus justifies calls for increased investment in knowledge production and actions that ensure the knowledge produced at the universities addresses the problems of industries and citizens. This might require putting in place specialized funding instruments that promote research activities that address specific issues, such as industrial development and policy systems. One way to accomplish this goal might include (i) increasing the proportion of government research funding against the national GDP, (ii) encouraging industries to invest in research activities, and (iii)

sustaining existing international collaborations. One policy action that would encourage industries to invest in research is establishing incentives for industries that are R&D performers. Such incentives could include tax exemptions, flexible loan schemes, and support with the supply of human resources from public universities and R&D institutions. Another option would be to provide access to existing public research infrastructure and to upgrade the existing research infrastructure.

c) Human capital development is the key input to the whole process of knowledge production, diffusion, and use. However, there is still a low research capacity in terms of qualified researchers who are located in Rwanda. Thus, there is a need to enhance human capital development mechanisms. This requires an education system that is inclusive but is also capable of addressing special needs. The latter can be addressed by the higher education system, where specialized programs need to be developed. This issue can be addressed by creating joint programs with industry, short training courses, professional internships, or commissioned programs for special needs. Linkages between universities and industries need to be enhanced, and mutual trust needs to be developed through regular interactions, either in round table discussions or promotional events, such as research exhibitions.

d) Knowledge can contribute to economic growth and development when it is put into effective use. However, this remains a challenge in Rwanda. There is a need for knowledge commercialization (and knowledge use in general) frameworks that enable economic value creation from the produced knowledge. This implies the development of an efficient and user-friendly Intellectual Property System that enables inventors and innovators to benefit from their intellectual property. This, however, first requires an awareness-raising campaign about existing IPR regimes and associated laws. Moreover, IP registration mechanisms need to be user-friendly and not time-consuming. This can be achieved by building capacities for technical evaluations of different IP regimes. A local IP panel of experts can be put in place to build such a capacity. Technology transfer offices need to be strengthened at universities and R&D organizations.

e) The findings in this thesis demonstrate that value chains in the agricultural sector in Rwanda are a potentially fruitful policy instrument that can be used to organize innovation activities in the agricultural sector. However, there is a need to smoothen relationships

between value chain actors, particularly the relation between farmer-university and industry-university. Policy tools, for example, innovation platforms, Farmers Field Schools, and entrepreneurial discovery groups can be explored for stimulating and sustaining these relationships. These tools can also contribute to strengthening interactions between actors for knowledge production and use, which remains a significant challenge across the entire Rwandan innovation system.

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Paper I

The use of scientific knowledge for society development requires enabling frameworks that allow the connection between knowledge production and use. STI policies and institutional arrangement are seen as a point of departure for such enabling frameworks. However, there is a need for understanding how individual countries are addressing the STI policies and institutional-related issues as a means for increasing the potential for the use of scientific knowledge for development. This chapter assesses STI policy setting, institutional framework, and capacity building mechanisms in the Rwandan context. It discusses ways for operationalising research and innovation uptake frameworks based on existing driving and constraint factors for research and innovation development in Rwanda. A structured literature review, survey, and data mining were used for collecting needed data for this study. The study shows a promising progress in science, technology, and innovation policy and institutional framework development, whereas the lack of trust among stakeholders, low research capacity, lack of funding, and low collaboration among actors were the major challenges. The establishment of an operational national innovation system and a contextualised triple helix model were identified as among the better options to be explored for accelerating the facilitation of research and innovation uptake in Rwanda.

Keywords: Research, innovation, knowledge use, STI policy, development.

Research and Innovation Uptake Landscape in Rwanda: Analysis of the STI Framework

Parfait Yongabo

1 Introduction

Worldwide, developing countries are investing much effort in their socio-economic development. The aspired socio-economic development is expected to be achieved by means of adjusting development strategies that were solely based on natural resources and focus on the use of science and technology to address development challenges. The production of needed knowledge and its application are major drivers for making science and technology important to contributing to the needed socio-economic development. Research is considered as among the potential means for producing the needed knowledge whereas innovation is seen as the result of the application of knowledge for addressing the identified development problems (Bercovitz and Feldmann 2006). However, both research and innovation require a level of capacity that can be acquired through consistent scientific training and exposure. This echoes the importance of a comprehensive Science, Technology and Innovation (STI) framework that can facilitate major operations for the production and use of knowledge for socio-economic development (Clark 2002; Juma and Yee-Cheong 2005; Leslie and hUallachain 2007). Thus, STI organization is considered as a stepping-stone for the development paradigm shift in developing countries, as it was experienced in developed countries.

As a way of shifting from the traditional development approach merely based on natural resources export, some developing countries have opted for technology importation as a first step to ensure they exploit available natural resources for their local needs. This has stunted the motivation for local researchers to engage in

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developing their own technologies beneficial to their countries (Juma 2005). Some imported technologies have even failed to respond to local needs, highlighting the need for contextualization by local researchers who understand their own countries' contexts (Etzkowitz and Dzisah 2008; Lawton Smith and Leydesdorff 2012). However, to do this, there is a need to build internal capacities and establish facilitation mechanisms and conducive environments that allow the production and use of knowledge for addressing real societal problems (Juma 2016). This might require a sustainable investment in education, skill development, science, innovation and technology as a means for paving the way for the progressive shift from technologies importation to internal technologies development and adoption. However, it is essential to have an organizational framework that can accommodate changes and provide the needed operational environment.

The rethinking of development approach from resources-based economy to a knowledge-based economy has caused development stakeholders to pay attention to policy and institutional framework as key facilitating instruments to institutionalize the production and use of knowledge for development (Amsden 2001; Etzkowitz and Dzisah 2008). However, this also requires systemic operational and organizational structures that favor active interactive learning processes for knowledge generation, transfer and application (Chaminade et al. 2018; Lundvall 2010). Knowledge institutions, mainly academic and research institutions are recognized as major sources of knowledge necessary for the development and economic transformation. Whereas industries and policymakers are considered as major end-users of produced scientific knowledge. However, there is the long-lasting claim from end-users that knowledge generated by knowledge institutions remains not available and accessible, and in some case when it is accessed is less responsive to their problems (Bercovitz and Feldmann 2006; Mueller 2006).

This is mainly due to the observed gap between the production of knowledge and the application of knowledge in support of development in most developing countries (Lawton Smith and Leydesdorff 2012; Göransson 2016). The alignment of government structures and development of technological imperatives could be important for facilitating the application of produced knowledge and problem-solving approaches that consider research and innovation as means for development (Juma and Yee-Cheong 2005; NCST 2015). This is likely to depend on proper STI policies and institutional frameworks. However, STI policies seem to be generic in many cases leading to less effective implementation and facilitation in positioning STI in the development process. Thus, there is a quest for a good understanding of how structures and working environment in a specific context can contribute to enhancing the facilitation of production and use of knowledge for development, particularly in developing countries. In relation to this, this chapter uses the Rwandan case to explore the research and innovation uptake landscape through the understanding of efforts that are being invested for accelerating the production and use of scientific knowledge for socio-economic development. An assessment of the STI policy setting, institutional framework, capacity development and discussion on ways for operationalizing research uptake frameworks based on the Rwandan context are presented to underpin this exploration.

2 Background: Contextual and Theoretical

2.1 Research and Innovation Uptake: A Need for Rwanda?

Research uptake is viewed as effective utilization of research-based evidence by research end-users (policymakers, industries, etc.) in order to improve development practices that lead to positive development outcomes with a realizable impact on socio-economic transformation and life standards improvement. At the same time, research uptake is considered to be a systemic and strategic process encompassing the absorption of research outputs and undertaken facilitation processes for the benefits of the society at large (Nguyen 2014; Ahmed 2016). The whole process of becoming aware, accessing and using research outputs by end users requires a comprehensive facilitation mechanism (Adolph, Herbert-jones and Proctor 2010; Nguyen 2014). The latter might take into account the institutional and policy frameworks as starting points for the organization of the process facilitation. However, other specific factors linked to the context need to be explored, such as research production capacity, STI promotion and stakeholders' interaction in general, among others. The organization of research and innovation uptake is seen as a challenge in many parts of the world due to issues mainly linked policy goals and directions concerning STI (Iizuka et al. 2015). To address these issues, analyzing the research and innovation landscape can be a starting point. The main components of the landscape mainly include institutions, their functions, policies and interactions among institutions. These landscape patterns are likely to have different shapes depending on the context and can be linked to standard concepts like National Innovation System and Triple Helix Model.

The analysis of the research and innovation uptake process in the Rwandan context is relevant because of the high demand for knowledge and skills to address Rwandan socio-economic development needs. The small land, limited natural resources, high population density, landlocked geographical location and the historical background explain the high demand for knowledge and skills to supply appropriate technologies and innovation to address development challenges. Based on the current challenges, there is a high commitment from the Rwandan government for investing in technology-based solutions and building internal capacities for knowledge production. This is expressed in most national development plans and programs, in most cases expressed under the "Knowledge-Based Economy" concept (Republic of Rwanda 2012; MINECOFIN 2013, 2017). With the expressed high demand and high commitment, there is a need to understand how the facilitation process for knowledge production and application is structured and what can be better options in the Rwandan context for materializing the high commitment and meet the demand. A comprehensive analysis of the STI framework can contribute to addressing this issue based on the role of STI in the whole process.

2.2 Does STI Framework Matter?

Science, Technology and Innovation (STI) are important for supporting the development of technical skills that respond to community needs and economic growth demand. The integration of STI into development is mainly organized through STI programs, which need tools and organizational framework for their success. STI Policies are among key facilitating tools that are likely to lead to development outcomes resulting from the use of scientific and technological knowledge. However, these policies tend to be generic, which in many cases might lead to less efficiency or unexpected results. It is important to analyze how structures and working environment affect both the formation of those policies and their implementation and outcomes in a specific context (Havas 2002). The importance of STI policies in supporting economic transformation can be observed in the case of the East Asian Tigers (Taiwan, Singapore, Hong Kong and South Korea) (Hobday 1995), where flexible policies allowed the development and adaptation of knowledge for the technological development which resulted into a remarkable economic performance.

The relevance and impact of STI policies are linked to policy goal setting and priority setting in line with the development goals. The focus of STI initiatives may differ from country to country depending on the development strategy and resources as well as operational conditions. This also can determine how STI policies are framed in different countries (Jacobsson and Bergek 2006). In most cases, science policies are separated from technology policies as well as innovation policies. There is no clear cut between these policies, except the way policymakers approach them. Science policies are generally aimed at promoting science in the education system and research institutions while technology policies focus on the development of technologies in areas influencing society's development. Innovation policies typically consider the complexities of innovation processes and facilitate interactions among relevant institutions to ensure quality and socio-economic impact resulting from their relationships (Dodgson and Bessant 1996). In some other countries, research and innovation policies are combined, there are also possibilities of combining research, science, technology and innovation under the same umbrella as a policy. This explains the importance of understanding differences and major orientations of STI framework in individual countries in order to understand how they can contribute to orienting the integration of knowledge into the development process.

According to Ergas (1987) in his analysis of technology policies, countries with high investment in R&D typically define their policy objectives as "*mission-oriented*" whereas countries with medium investment shape theirs as "*diffusion oriented*"; there are others which combine the two objectives, mostly New Industrializing Countries. The policy objective defines the nature of innovation to be focused on and the actors of interest. Mission-oriented policies tend to promote radical innovations aimed at solving state problems whereas diffusion oriented policies favor incremental innovations aimed at addressing society problems through technology uptake at different levels and in different forms. The nature and level of impact of R&D initiatives are

then based on policy objectives as well as the operational environment (Ergas 1987; Dodgson and Bessant 1996; Havas 2002).

Taking the example of the United State of America, France and the United Kingdom as discussed by Ergas (1987) in his study of technology policies in these countries, clear differences in technology impact can be identified, although the policy objectives were the same across the three countries. The differences are based on approaches and structures (operational environment) in each country for implementing policies. Bureaucracy and centralization in the UK were at the origin of less effective technologies generated from R&D activities while the high level of autonomy and flexibility in France allowed technology to have a more relevant impact than in the other two countries. The USA had a high level of control in technology dissemination as the UK, but due to the wide market and resources in the USA, technologies have reached other socio-economic sectors beyond the military sector, which was a priority. From this, it can be observed that policies and institutional frameworks are of significant importance for having impactful R&D initiatives, although, external factors in the operational environment can influence their objectives as well.

With the case of Hungary during the late 1990s, instantaneous changes in structures and institutions did not favor the development of STI policies, causing innovation systems to underperform. But after 2000 with STI policies adoption and stabilization, R&D activities showed outstanding success and the use of technologies from these activities by industries increased; this led to a noticeable change in the economic performance of the nation (Havas 2002). Appropriate policies can thus define the level of success for research and innovation in the economic transformation to a certain extent. From these perspectives, it is clear that the STI organizational setting and policy framework are at the base of interactions that promote the use of scientific knowledge for development. Then, effective STI policies can play an important role in economic development by facilitating these interactions leading to industrial transformative development that improves the technological capabilities of firms with knowledge at the center of operations (Dodgson and Bessant 1996). STI policies support to socio-economic development as a facilitating tool may vary from one country to another depending on economic structures and working environment at a specific place. This explains the interest in exploring the STI framework (policy and organization) as a point of departure for developing efficient research and innovation uptake frameworks that can accelerate the use of knowledge for development in Rwanda.

3 Methodology

This study focuses on the Rwandan STI framework as a means for exploring the research and innovation uptake landscape, considering the patterns of policies, institutions, capacity building and interactions. It uses mixed methods, including structured review of existing documents, survey and secondary data mining. The review

included scientific articles, scientific reports, official reports, programs and policy documents. Whereas for the survey, research managers at universities and public agencies, researchers and entrepreneurs were consulted categories. Secondary data were acquired from different databases in offices in charge of STI matters in Rwanda.

The survey included two series, the first round was conducted in April 2017, it was based on a set of generic questions sent online to 10 top managers in public agencies and universities. Seven persons over 10 contacted responded to the questions. The questions mainly focused on enablers for research and innovation uptake, stakeholders' collaboration, synergies in research management and facilitation; and research infrastructures and capacity building, among others. Depending on the structure of each institution, I considered offices having technology transfer in their mandates. Respondents in government institutions and academic institutions were senior managers. For entrepreneurs, the Private Sector Federation was consulted as the overall umbrella for the business sector in Rwanda. Contacted institutions include the University of Rwanda (UR), University of Kibungo (UNIK), National Industrial Research Development Agency (NIRDA), Rwanda Agriculture Board (RAB), National Commission for Science and Technology (NCST) and the Department of Science, Technology and Research in the Ministry of Education (DSTR, MINEDUC). After the first round of April 2017, follow up discussions were conducted in December 2017 with a semi-structured interview based on the feedback provided in the initial online consultation and follow up questions were related to policy and institutional framework as well as well collaboration among stakeholders. Follow up interviews lasted for 30 min to 1 h and all the 10 initially contacted stakeholders were included.

To complement the information from the literature and the survey, available data from databases and reports of recently completed studies related to R&D and STI in Rwanda and Africa at large were used. Data on higher education matters were obtained from the Rwandan Higher Education Council. Whereas, data on research capacity and skills demand were acquired from the National Research and Development Survey of 2015 as well as the Africa Capacity Report of 2017.

Collected information was organized and analyzed systematically in order to analyze the main components of the Rwandan research and innovation landscape, which is the main objective of this chapter. Survey data were arranged based on key predefined parameters in order to be able to display information in the form of diagrams and info-charts. Predefined parameters included the category of actors, perception on the interaction among actors (synergy), identified challenges and perceived enablers. For quantitative data, cross-tabulation was done for producing summary tables. Analyzed variables were the trend in time for capacity building in higher education (estimated using the number of graduates per level of education over time).

4 Institutional and Policy Frameworks for Research and Innovation Management in Rwanda: A Systemic Review

Policies and institutions are among the potential components for setting organizational systems to support the production and use of knowledge for society development. In the case of Rwanda, as a landlocked developing country with limited resources, more comprehensive policy and institutional frameworks that ensure synergies among actors for meeting the common development goals are imperative. However, the establishment of such frameworks requires a good understanding of the system setting as a point of departure. This section of the chapter elaborates on the STI policies setting and institutional arrangement in Rwanda as mean of highlighting what exists and what would be the best recommendations to be considered in developing/adapting the needed comprehensive frameworks.

4.1 Research, Science, Technology and Innovation Policy Setting in Rwanda

Efforts have been invested in establishing STI policies and their instruments that are inspired by the government plans and programs in order to ensure that policy goals lead to the expected socio-economic development. The initial National Education Sector Policy of 1998 was a point of departure in reviving the Rwandan education sector after the tragedy of the Genocide against Tutsi of 1994 (UNESCO 2015). This policy paved the way for other policies that followed as a way of taking a wide sector approach. In 2003, a new education sector policy was developed with considerations for developing other specialized subsector policies for enhancing the production and use of scientific knowledge (MoESTSR 2003). The National Science, Technology and Innovation Policy of 2006 is among the developed policy in order to provide avenues for STI promotion in Rwanda (Murenzi and Hughes 2006). The efforts in developing policies were accompanied by the development of policy instruments for ensuring their implementation. However, consulted stakeholders perceived the implementation of policies to be slow due to overlap in policy goals, lack of human capacity, lack of financial means, low collaboration among actors and lack of a comprehensive institutional framework for coordination.

In relation to the low implementation of policies, stakeholders highlighted concerns on the policymaking process, which is seen as a top-down with limited consultation with concerned stakeholders. The use of international consultants with less knowledge of the Rwandan context is also seen as among the factors that slow the implementation process. Because most of the policies consider less the realities of the local context. They are formulated in a normative way based on what succeeded in other countries that have made considerable progress in STI. This, in turn, affects the implementation because the policy custodians in Rwanda in most of the cases

fail to produce policy instruments that respond to the policy goals. To address this, Rwanda has started to build its internal capacities and encouraged the collaboration of international consultants with local consultants who understand the context. The policy-making process now is taking a more comprehensive approach with an emphasis on consultation with stakeholders in different forms and at different stages.

> As the Ministry of Education, we did a lot in the past in developing the STI policy but still, the clear research policy is in need and there is still a challenging issue linked to research and innovation strategic plans, they have been developed but not yet released, M&E mechanisms and clear policies implementation mechanisms. Much effort should be put in strategic consultation frameworks so that people can exchange experiences and lessons learned from other places (inside and outside the country). The national dialogue "Umushyikirano" can be a good example of a consultation framework were policy recommendations can emerge. If it can be possible to have sector-based consultation frameworks, it can contribute a lot in policy implementation, especially research and innovation oriented policies as they deal with how to address real problems in the society (Senior STI Manager).

The STI policies are aligned with their supporting policies, policy instruments and their inspiring government plans and programs in order to increase chances for successful implementation and impact. Figure 1 provides details on the key STI policies and other aligned policy instruments and government plans. In addition to national policies, academic and research institutions also prioritized the development of research and technology transfer policies to ensure that conducted research is of high quality, and responds to community demand. In 2006, the former National University of Rwanda developed its first research policy and other Higher Learning Institutions (HLI) both public and private followed with their own research policies; about 91% of academic and research institutions in 2010 had research and technology transfer policies (Butera et al. 2012). In addition to Higher Learning Institutions,

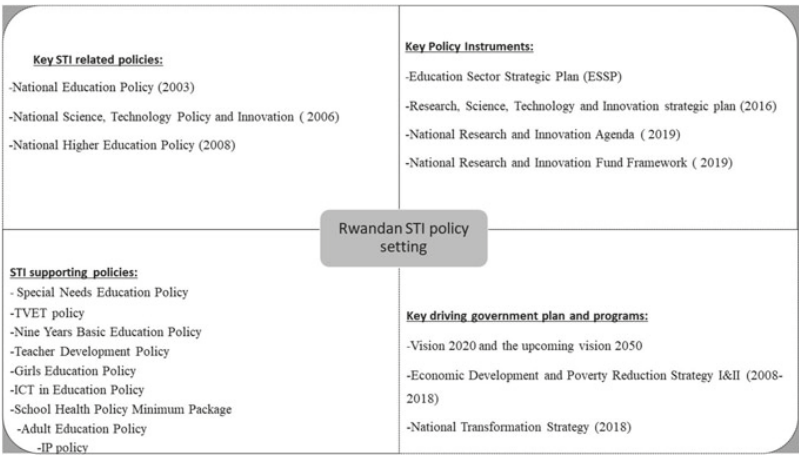

Fig. 1 STI policy setting in Rwanda *Source* Author's' own compilation based on policy documents and reports

other research institutions have moved on with developing their research policies and technology transfer policies as a way of strengthening the production of scientific knowledge and its use for solving the societal problems. Supporting policies in strengthening the education sector as a mean of increasing the capacity for knowledge creation and acquisition were also developed. To allow the facilitation of the use of produced knowledge, policies on intellectual property rights and commercialization were put in place as well. Although, their awareness remains very low among the stakeholders.

4.2 Institutional Frameworks for Research and Innovation Management in Rwanda

To ensure the coordination of STI activities in Rwanda, structures have been established to facilitate the interactions and smooth implementation of activities responding to the overall goal of producing and using knowledge for development. These structures as in other environments in the initiation phases faced a series of review and restructuring for the sake of achieving stable and delivering structures. Over a long period, all activities related to STI were overseen by the Ministry of Education (MINEDUC) until in 2017 where the National Council for Science and Technology (NCST) was given the overall mandate to coordinate national Research, Science, Technology and Innovation activities. As a way of supporting this national coordination organ, there are sector-specific entities that are in charge of promoting STI in specific sectors. Those include the National Research and Industrial Development Agency, the Rwanda Agriculture Board, the Rwanda Biomedical Center and the Rwanda Standard Board, among the major. The Rwanda Development Board has the overall mandate for facilitating Intellectual Property Management in collaboration with the Ministry of Trade and Industries. However, it is not clear to stakeholders how these organs collaborate and complement each other. Consulted stakeholders expressed their views on a remarkable duplication of efforts among most of these institutions and lack of consultation and collaboration. Referring to studies on the performance of the National Innovational System that have proved that synergies among actors and effective organizational structures are imperative for knowledge dissemination and use (Lundvall 2007; Edquist 2008), it can be envisageable for Rwanda to rethink about its institutional organization and assignment of mandates.

The proper assignment of mandates might have a significant functional improvement in the current institutional framework. According to the normative function of institutions in the triple helix model, as described by Lawton Smith and Leydesdorff (2012), the current Rwandan institutional framework shows the arrangement of institutions according to their prescribed function but doesn't have strong expected linkage among the functions, which explains the lack of operationalization of the normative functions. This is also linked to unclear and duplicated mandates for some institutions. Institutions have their mandate stating what needs to be done but they

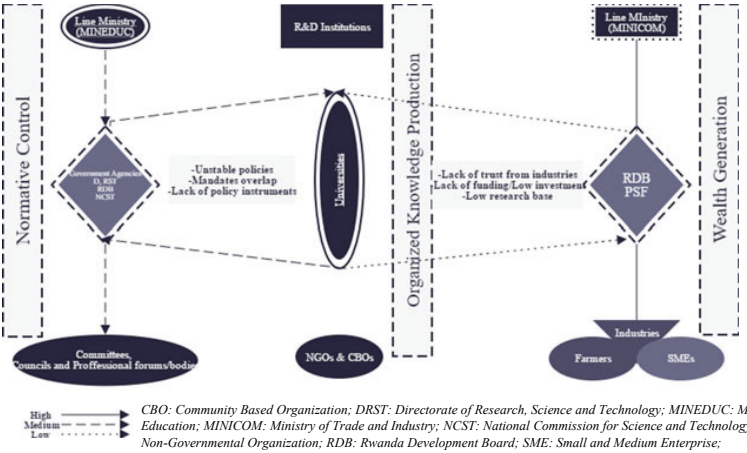

Fig. 2 Current Rwandan functional institutional framework for research and innovation management based on Lawton Smith and Leydesdorff, 2012 triple helix functions *Source* Authors own compilation based on policy documents and reports

are still missing clear strategies on how to do that. Figure 2 shows the status of the institutional framework for research and innovation management in Rwanda based on their predefined normative functions and the perceived level of interactions by stakeholders.

As highlighted in Fig. 2, knowledge institutions, which are universities, research and development institutions and other Non-Governmental Organizations (NGOs), including community-based organizations are expected to accomplish the organized production of knowledge. Knowledge production in this context focuses more on research-based knowledge. The contribution of these institutions may be through active direct involvement or indirect involvement. This production of knowledge is to some extent organized and managed in regulatory and administrative way under the control function umbrella accomplished mainly by the public agencies mandated for research, science, technology and innovation. Whereas the use of the produced knowledge is expected to be performed by the business sector through the valorization of IP (commercialization) and industrial development. The private sector and the line ministry in charge of commerce and industries and other aligned agencies like RDB facilitate this function of wealth generation through the use of knowledge. Small and Medium Enterprises are considered as basic operational units to accomplish that function. These three functions can be performed if there are strong operational links among the performers. There is a moderate link between the controllers/facilitators and the knowledge producers, whereas there is a low link between the knowledge producers and knowledge users for wealth generation. Several factors affect the levels of linkage, including unstable/unclear policies, mandate overlaps and lack of policy instruments for the needed efficient control. Whereas the lack of trust among

stakeholders, low investment and low level of research production are among the factors slowing down the linkage between knowledge production and use for wealth generation.

> *- The level of synergy is still low. The interactions are based more on individual contacts, rather than institutional frameworks. There is a lot said about PPPs but there are no national mechanisms to drive them forward. For example, at the institutional level, it should be mandatory to have Advisory Committees as part of the regulations that are enforceable. At a national level, the PPPs and Triple Helix initiatives can be supported through Government subsidies and tax rebates (Research Manager at University).*
>
> *- The level of synergies is still low even though things are getting better due to new strategies, which are being put in place (STI Manager in Public agency)*

The above challenges are seen as common continental challenges in Africa. Generally, in regards to the development of STI policy and institutional frameworks, as highlighted in the African Capacity Report of 2017, there is promising progress in most of the African countries. However, STI related policies implementation was reported as a critical problem for most African countries, where about 84.4% of African countries have policies in place but only 40% have clear processes for policy implementation in place (ACBF 2017). This is the case also for Rwanda though it is not easy to quantify the pace of implementation of the various STI policies as they are subject to many reviews before they achieve the stage of impact and this explains the instabilities and overlap of institutional mandates as well.

5 Promotion of Higher Education System and Building Internal Capacities in Rwanda

The development of the higher education system is among the potential ways to build internal human capacity that can respond to the local development needs. This is part of the Rwandan strategic actions to make STI among the core drivers for development. The Rwandan education sector is increasing opportunities for higher learning institutions to operate in Rwanda and stimulate competitiveness among the graduate on the labor market. In the same line, about 30 private higher learning institutions were accredited to operate in the Rwandan academic sector and one public university (University of Rwanda) with six colleges in disciplines of Agriculture, Arts and social sciences, Business and Economics, Health Sciences, Education Sciences and Science and Technology was established in 2013 for efficiency and effectiveness (HEC 2019). To stimulate practical oriented training and the generation of technical skills responding to the community demand, the GoR established the Work Development Agency (WDA) in 2008 to coordinate and ensure the quality of practical training. This aims the production of employable graduates to specific labor market needs, responding to the technical skills needed for development. Under WDA, the Rwanda Polytechnic was established in 2017 with eight Integrated Polytechnic Regional Centers (IPRC) and 22 Technical Vocation Education and Training

Table 1 Awarded degrees from 2000 to 2015 in Rwanda

Academic year	Diploma	Bachelor's degree	Postgraduate degrees (PGD, M.Sc. & Ph.D.)	Total
2000–2002	780	1591	0	2371
2003–2005	1536	7340	41	8917
2006–2008	2639	16,666	362	19,667
2009–2011	7048	28,632	1551	37,231
2011–2015	4713	28,793	3347	36,853
Total	**16,716**	**83,022**	**5301**	**105,039**

Source Rwandan Higher Education Council (HEC) 2016

(TVET) certificate courses were designed, of which six are agriculture oriented as agriculture is among the main economic sectors of the country (WDA 2018).

In addition to the higher education system promotion, research capacity building has been prioritized as well, even though the base is still low. Table 1 shows the trend in degrees awarded in higher education in Rwanda over 15 years period (from 2000 to 2015). Despite this positive trend, the number of qualified and active researchers is still low. According to the research and development survey of 2015 with 2013–2014 as a year of reference, most active researchers in the higher education sector were MSc holders (51%). Whereas active staff to support research activities had a Bachelor's Degree in both government and private sector at a rate of 39% and 40% respectively (UNESCO 2015). The number of qualified staff for conducting research is still low across the country; for example, the University of Rwanda in 2014 had only about 19% of staff with PhDs (UR 2014) and the same situation is reported in the Agricultural Research and Development Indicators Factsheet, 2018 where only 21.9% of researchers in agriculture domains are PhD holders (Flaherty et al. 2018). To bridge this gap, a number of collaborations have been initiated for capacity building and training programs at advanced levels are being established.

Although the education system and human capacity are being developed in Rwanda, stakeholders expressed the need to consider the development of research infrastructure and funding capacity. This is among the core challenges for most of developing countries as they have a high dependence on external funding and donations for their research budgets and infrastructure development (Juma 2006; Göransson 2016; ACBF 2017). As a way of approaching the issue, African leaders, in their ordinary session of African Union Head of State and Government Summit of 2014, committed to investing at least 1% of the national GDP in Research and Development (R&D) and they emphasized on the importance of the integration of STI in all African development agendas. The commitment was a good start, however, the current effort in its implementation signals difficulties for many Africans countries. This can be explained by the continental average of 0.5% of the GDP invested in R&D, even some countries are not yet able to consider R&D in their national budget (ACBF 2017).

For Rwanda, the R&D investment was estimated at 0.2% of the national GDP in 2015 (UNESCO 2015), although the commitment is 1% by 2020 and 4% by 2050 (Gatare 2016). The current share of the GDP for R&D seems to be small compared to targets set and to the practice in developed countries where R&D made a progress. Thus, it would be in the interest of Rwanda to explore possibilities to meet such ambitious commitments in addition to the donor led research funding. The encouragement of industries to invest in R&D would be one of the options. This might be done through setting incentive schemes for industries that invest in R&D and give a level of autonomy to research institutions for the smooth running of joint research activities with industries. The established National Research and Innovation Fund might be a starting point to exit from donor led research funding and expand horizons for the Rwandan research funding by interesting industries to invest in research. This funding instrument will need to consider a more inclusive approach that stimulates long-term collaboration between the knowledge producers and knowledge users. It might be advisable to direct effort to transdisciplinary applied research and give less interest to blue-sky research. This might also be a way of valorizing considerable investments done for infrastructures to support applied research and innovation, including ICT infrastructures, the establishment of centers of excellence and scientific laboratories as well as innovation hubs and incubators.

6 Driving and Constraint Factors for Research and Innovation Uptake in Rwanda: Towards a Performing STI Framework

The organization of knowledge production and its use is context-specific as discussed by Lawton Smith and Leydesdorff (2012) and depends on available resources, actors and their interactions. For the case of Rwanda, consulted stakeholders had relatively similar perceptions on the major considerations for shaping research and innovation uptake in Rwanda, mainly in the view of driving and constraint factors to promote the use of research outputs for national development. Strong policy and institutional frameworks were among the factors perceived by stakeholders as important, followed by the researcher's capacity building through higher education and mentorship, and collaboration among stakeholders. Research funding and access to adequate infrastructure were also mentioned as main drivers to high quality research outputs that can have development impact and meet community needs. Both literature and survey results confirm that progress has been made in the areas of policy development and institutional structuring; however, gaps in policy implementation, stability and consistency are still observed.

Although there has been progress, some constraints to research and innovation uptake are still observed. Consulted stakeholders in the survey repeatedly mentioned the lack of trust among actors to be among the key constraints. It was highlighted from the academic side that there is concern about the protection of intellectual properties

whereas industries are concerned about the research quality. The lack of trust and low research quality may be at the root of the lack of interest among industries to invest in research and limited interactions between industries and research institutions. This lack of interaction between industries and research institutions is a hampering factor for having a performing framework that allows the flow of knowledge among socio-economic actors in Rwanda. According to Lundvall (2007), interactions between firms and knowledge infrastructures (universities, research institutions) are among the indicators of a sustainable innovation system. If interactions are weak or non-existent, it may be hard to realize national economic growth resulting from knowledge dissemination and use. This seems to be the case for Rwanda where it is hard to see the contribution of scientific knowledge to national economic growth. This can be observed by looking at the commercialization of research outputs and the use of knowledge to solve the community problems, which is still very low.

> *The main issue is the quality of researchers and research output. The business side is interested in high quality research outputs that directly impact business performance such as increased sales, increase in production and productivity, loss reduction, risk mitigation. But most of the research outputs are unusable to the industry. What I am trying to say is that the reports are good but cannot benefit the end user practically* (*Research Manager at University*).

In addition to the need for trust, other considerations in support of the ultimate use of knowledge through the aspired research commercialization and general community use include policy and institutional framework. The latter can pave the way for the proper establishment of collaboration framework, research funding and capacity building, among other intermediate factors to driver research and innovation uptake in Rwanda. The proper collaboration frameworks may lead to the needed trust and appropriate Intellectual Property Right (IPR) use. Whereas, the research funding supports the infrastructure, general research activities and incentives for research. The capacity building in different forms, like formal training or continuous learning on job supports skills development. The interconnection among these factors is likely to lead to the high quality research, motivation of research and credibility and availability of credible data/information to end-users, which are among perceived key attributes for increasing the research uptake. Figure 3 illustrates the connection among the factors that may contribute to enhance the research and innovation uptake and their relationship as indicated by arrows.

7 Analytical Perspectives

The Rwandan context as analyzed demands for a more comprehensive systemic approach to organizing the creation, diffusion and use of knowledge. This poses an interest in major components of the system and interactions among these components for having a functional system. The described STI framework in terms of policies and institutions can be a point of departure in building such a system, like the National Innovation system as suggested by its pioneers (Nelson, Freeman and Lundvall).

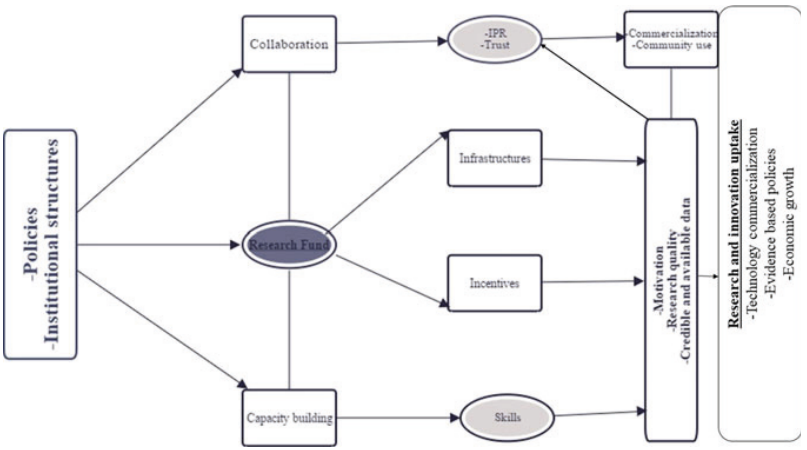

Fig. 3 Diagram of perceptions of drivers for research and innovation uptake in Rwanda *Sources* Survey by the author, 2017

According to Lundvall (1992), the National Innovation System is considered as a comprehensive framework that can facilitate the use of research, science, technology and innovation to support the society development. It considers knowledge as the main capital and learning as the core process. In this framework, economic structures and institutional settings shape the interactions that ensure the co-evolution of knowledge generation and diffusion among the knowledge producers and end-users (Freeman 1995; Lundvall 2007, 2010). The current institutional setting in Rwanda shows a remarkable disconnect to support interactions that are necessary for the use of produced knowledge for responding to the society problems related to industrial development and entrepreneurship. The observed disconnects reflect the non-existence of the needed comprehensive system; however, there is an expression of interest for that system. This can be confirmed by the government's commitment in different plans and programs that advocate for a knowledge-based economy.

Based on the institutional arrangement as described in Fig. 2, interactions among actors for accomplishing their roles as per their defined mandate might be supported by an operational tool that can help the organization of ways for actors' engagement. The Triple Helix Model is suggested as among such tools in the context of developing countries (Etzkowitz and Dzisah 2008). The Triple Helix Model (THM) is described as a tool to promote research uptake by ensuring the interaction between three clusters of actors including universities/research institutions, government/public institution and private/business institutions. It considers universities to play the central role in interactions for knowledge production and use as opposed to the NIS concept where firms are considered to play the central role in these interactions (Etzkowitz and

Leydesdorff 2000; Lundvall 2005). The two concepts have in common the consideration of interactions among actors and institutional capabilities, both creative and diffusion capabilities.

Considering the Rwandan context in terms of institutional setting, research capacity and the demand for skills to address the society as described in Fig. 2; it might not be realistic to confirm that the triple helix can work in the Rwandan context. However, it might be reasonable to take the triple helix model as a point of departure for developing a more contextualized tool for Rwanda. Nevertheless, some preconditions might need to be taken into account. Those include trust, capacities of actors and creation of avenues for interaction. Although, lack of trust among actors and low research quality were reflected as among the compelling factors for research and innovation uptake. This low level of trust among actors can be interpreted as a result of operating in silos, which precludes building mutual trust through a continuous learning process.

The interactive learning processes might be facilitated by the adoption of an education system that fosters exposure of students and university researchers to industries in a way that industrial practices and academic practices are harmonized and complementary with mutual responsiveness to problems. Lundvall (2005) expressed the same view in discussing National Innovation Systems in developing countries, emphasizing the importance of early interactions among firms and knowledge infrastructures with small initiatives that might result in significant outputs over time. This to some extent proposes a bit different approach to what many developing countries, including Rwanda, are trying to adopt. They are trying to invest in big infrastructures like "Science Parks" and "Monumental Innovation Hubs" without the fundamental grounds for running and sustaining those big investments; such investments may result in the waste of the little available resources. In the Rwandan context, a start with diversified incubation centers playing the intersection point between universities and industries might be a good option.

Whereas for the low research quality and limited resources, consultative approaches and experience sharing can enhance the relevance and the quality of research as well as the consolidation of efforts to maximize the limited resources. Etzkowitz and Dzisah (2008) puts this forward as one of the benefits of THM, considering the possibilities for resource circulation among the spheres of actors (Public-private sector-Universities). This also might be a way for ensuring the effective use of available human resources through the facilitation of human resources circulation at different levels (macro & micro) within and among institutions. Although, this can be seen as a short-term solution for progressing with building the needed capacity.

8 Conclusion

The Rwandan Research and Innovation uptake landscape is characterized by different patterns in terms of efforts that are being invested for establishing mechanisms that accelerate the use of knowledge for socio-economic transformation. The development of the STI policy framework and aligned institutional framework are among the

major progress made. However, capacity building and collaboration are still among the priorities that need attention. The funding of research and innovation is still challenging, as it is more donor-driven. There is a hope that the establishment of the National Research and Innovation Fund (NRIF) will contribute significantly to addressing this issue. This NRIF can be a starting point for attracting local industries for investing in research. This is likely to happen if the NRIF targets research that is responsive to industrial problems.

Human resource capacity-building efforts have been invested, although there is still a high demand for qualified researchers. Specialized capacity building schemes can be among the ways to approach capacity building issues. Collaboration with other development partners is a potential solution, which can be sustained through the establishment of joint training programs and exchange programs that provide room for exposure to the Rwandan researchers and access to modern infrastructures that are not available in Rwanda currently. Establishment of centers of excellence and research laboratories, as well as innovation hubs and incubation centers, are good signs of internal capacity development that can ensure the possibilities for developing contextualized needed technologies that are responsive to the society problems.

Although there is investment in all these efforts, there is a need to put in place a comprehensive framework that facilitates the use of these resources and capacities for producing and using knowledge to address the development challenge that Rwanda is facing. The construction of an operational National Innovation System can be one of the options for organizing the creation, diffusion and use of knowledge for economic growth at the national level. This can facilitate the needed availability, accessibility and use of knowledge. Given the challenges for the facilitation at the national level, it is recommendable to organize the research uptake at a sectoral level based on specific socio-economic sectors in Rwanda. This can be a strategic and systemic move in operationalizing the NIS. However, this needs to be coupled with promising tools that help to organize linkages and collaboration among the actors. A contextualized triple helix model was identified as among the tools that have potentials based on the Rwandan context.

Overall, the research and innovation uptake landscape in Rwanda presents a mosaic of initiatives that need to be harmonized and arranged in a way that they are coherent and complementary. This can be achieved through integrated planning that considers the alignment of development goals and research efforts as well as set up platforms for stakeholders' interactions and consultations. The importance of joint efforts between universities, government and the private sector deserve particular attention.

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Paper II

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Constructing the national innovation system in Rwanda: efforts and challenges

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ABSTRACT

The building of sustainable innovation capabilities in Africa requires an innovation system capable of producing, disseminating and using new knowledge. This paper assesses the process of constructing the National Innovation System (NIS) in Rwanda. It is posited that consensus on and acceptance of the concept of NIS among stakeholders is crucial in the early process of constructing an efficient and dynamic innovation system. Primary empirical data are presented for the case of Rwanda and analyzed in a regional context. The study shows that the NIS concept is generally being integrated and utilized in the process of building sustainable innovation capabilities in Rwanda. In particular, Rwanda exhibits promising progress in the process of establishing and reinforcing infrastructures and institutions as well as policies to promote innovation. However, there are still challenges associated with low research capacity, low level of interactions among stakeholders, limited financial resources as well as lack of coordination framework, all of which contribute to hampering the building up of sustainable innovation capabilities.

KEYWORDS

Research; innovation; innovation system; interactive relationship; innovation capability; STI Policy

1. Introduction

When the notion of National Innovation Systems (NIS) was offered some 30 years ago, it provided what would become a powerful conceptual tool for analyzing the complex interactive relationships between actors, institutions and companies that determine a country's innovative performance. Pioneering works by Christopher Freeman (1995), Richard Nelson (1993) and Bengt-Åke Lundvall (1992) laid the foundation for dissecting the knowledge generation system and for exposing the inner workings of how new technology and information effectively flows within that system.

Since then, the NIS under scrutiny can mostly be found in the advanced economies of the North and, to a lesser extent, in newly industrializing countries. Less empirical attention has been paid to countries with more rudimentary or even embryonic national innovation systems and the construction phase of national innovation systems. Can well-

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functioning innovation systems in such countries be built on demand as specified in national policies or are they a result of organic trajectories and path dependencies in the sense that they follow the economic progress of an economy and not the other way around? Can developing countries with fragmented innovation systems leapfrog the stages of classical development theory and design effective innovation systems in support of national goals? And, if so, what are the basic requirements in terms of institutions, actors and policy?

Classical development theory tends to regard the institutional set-up and functioning of advanced economies not only as a goal for late coming economies but also as a blueprint to be followed. In the early construction phase of NIS, it might be more prudent, as pointed out by Lundvall (2012), to not focus so much on what is missing but rather on what actually exists. Such a pragmatic approach demands empirical data not only on institutional set-ups and on inventory of policy measures but also on interactive learning capabilities as well as perceptions on NIS by the principal actors. It is our contention that a general consensus on and acceptance of the concept of NIS among Science, Technology and Innovation (STI) stakeholders is essential in the early process of constructing an efficient and dynamic national system of innovation, in that it establishes a common conceptual foundation and provides different stakeholders with a means to better align institutional responsibilities to overall developmental goals as well as to counteract policy inconsistencies.

This paper analyzes the ongoing process of constructing a National Innovation System in Rwanda in a regional context. More specifically, the paper examines how the concept of NIS has been received by the STI community and how well it has been integrated into the capacity building process for sustainable innovation. Moreover, it identifies the prevailing perceptions of the STI stakeholders in Rwanda on what are the major challenges and obstacles in making science, technology and innovation an effective force for socio-economic development. In doing so, the paper contributes to the growing field of research exploring and contextualizing the NIS concept in a developing countries' setting.

In the following section, the underlying theoretical framework is discussed, with an emphasis on learning as an interactive process in the developing world. The research design is presented in Section 3, followed in Section 4 by an analysis of efforts made in the construction of NIS in an East African regional context. Section 5 examines the case of Rwanda and presents the results of a survey of STI personnel in that country. The insights and prospects for the Rwandan NIS construction process are discussed in the concluding section.

2. Theoretical background

2.1. Complex and interactive frameworks: connecting innovation and development

The surprisingly long-lived linear model of innovation was historically seen as driven by science pushes or market pulls. In the science push model, in vogue in the 1950s and 1960s, basic research was at the core of shaping technological innovations to be sent out to the market (Etzkowitz and Leydesdorff 2000; Manley 2002; Godin 2017). However, turning scientific knowledge into economic growth requires evolutionary

processes and interactive approaches allowing for multiple dimensions; in addition to economic aspects, social and environmental dimensions are among the critical ones. Such integrated approaches call for systemic mechanisms and operations (Lundvall 2010; Vertova 2014). The innovation system approach is one of the frameworks that can be responsive in this regard. However, it requires building both capacity and capabilities where human and institutional resources are considered crucial starting points. In addition, both industrial and absorptive capabilities are seen as main factors for an innovation system to prosper (Etzkowitz and Dzisah 2008; Chaminade, Lundvall, and Haneef 2018). The building of such capacities and capabilities requires a proper understanding of the frameworks as well as appropriate facilitation from varying perspectives.

A number of frameworks aiming at the facilitation of the use of knowledge have been established and tested in different contexts. Several frameworks consider learning and interactions as main processes and where institutions and knowledge are major components (Fagerberg, Bengt-Åke, and Srholec 2018; Leydesdorff et al. 2019). Key frameworks and concepts include networks, value chains, clusters, development blocks, complexes, innovation milieu, complex products and systems, competence blocs and innovation systems. These were developed for the sake of understanding the complexity of interactive learning processes occurring in the innovation process (Manley 2002). For the construction and success of any of these frameworks, it is important to take into account the emergence process, the inputs and available resources as well as the operational environment. The latter can be related to the social structures, institutional framework, economic structures, capacity and capabilities building structures (Alkemade, Kleinschmidt, and Hekkert 2007; Djeflat 2015). The interactions among the structures and facilitation processes are important for resources and human capital circulation in order to promote the use of knowledge for development (Etzkowitz and Leydesdorff 2000).

In most developing countries, particularly African countries, institutional structures were inherited or replicated from their colonial rulers. An example of this replication can be some university structures and curricula in British and Belgian colonies (Havas 2002; Etzkowitz and Dzisah 2008). This replication might affect the construction process of a contextualized system with structures that are responsive to local context issues and enabling the flow of resources among the actors. Endogenous capabilities are hard to build with research and education systems that do not fit into the specific context, and yet the education system is among the drivers of innovation propensity in any innovation system (Freeman 1995; Sawyerr 2004). The African emerging innovation systems, thus, are interested in building endogenous capabilities to establish stable and performing innovation systems (Scerri 2016). The construction of individual countries' innovation system in the context of emerging economies is likely to be linked to regional issues such as geographical location, higher education system, R&D performance and level of technological development (Jacobsson and Bergek 2006; Coenen 2006).

Depending on regional and local contexts, an innovation system can take different forms from the suggested initial concept referred to above. However, the adaptation and contextualization of the IS in a certain context require a proper understanding of the concept and exploitation of supporting instruments in terms of policy and institutional frameworks. The geopolitical patterns are key in the shaping of NIS in this case and it might be wise to position a NIS in its regional context for better understanding its construction process, as it is likely to be influenced by regional plans and

transboundary operations (Leydesdorff et al. 2019; Fagerberg, Bengt-Åke, and Srholec 2018; Coenen 2006)

2.2. National innovation system: an emerging model in developing countries

The concept of National Innovation Systems can be considered as a tool for analyzing industrial development and economic growth, but also as an approach to understanding the diversity and complexity of the contribution of knowledge and learning into economic growth (Lundvall 1992; Högselius 2005). The variations in the forms and nature that NIS can take depending on specific contexts are still a contentious issue. Lundvall (2007) made further steps in explaining the context-dependency of NIS by clarifying that the NIS concept, as designed for developed countries, cannot easily be replicated in developing countries because of differences in the level of knowledge production and economic structures.

With the context-dependency of NIS, Lundvall (2007) has further highlighted the need for understanding the NIS concept for developing countries and for focusing more on system construction and promotion in light of the realities and special contexts present in developing countries. He argues that it is rare to find firms organized and engaged in innovation processes at the earlier stage in developing countries, and interactions between firms and knowledge infrastructure are still limited. This reflects the need to understand local contexts for industrial development and R&D performance to produce, transfer, access and exploit knowledge for socio-economic development in different contexts, particularly developing countries.

The emergence of NIS in developing countries should not only consider internal capabilities but also the regional context that influences the institutional and policy performances (Scerri 2016). In the same vein of context specificity in developing countries, some observers have suggested the crafting of new concepts instead of adopting a NIS framework that is built on the idea of high organizational capacity and competence; conditions which are not yet in place (Lall and Pietrobelli 2003). However, the introduction of alternative concepts for developing countries would not make sense as argued by Lundvall (2007); it may be better to use alternative approaches in studying NIS in developing countries that fully consider the specific local contexts.

Freeman (1995), referring to Friedrich List's analysis of Germany in the 1800s, proposes that the understanding of higher education and research systems and their readiness to contribute to industrial development is a fruitful way to analyze developing countries' NIS. This can be a good starting point as organizational structures in developing countries are still not sufficiently mature to allow a smooth flow of knowledge and interactive learning processes between firms and universities. This limitation is due to the fact that most of the firms and knowledge institutions are at their embryonic stage, and knowledge production is still focused on basic research rather than applied/industrial research resulting in technical innovations to be used by industries (Etzkowitz and Dzisah 2008). In the context of the East African region, efforts toward building regional systems/frameworks have been initiated and are likely to contribute to shaping local interactions among knowledge producers and knowledge users. This highlights the need for considering the regional context in exploiting individual country's innovation system construction.

3. Research design

3.1. Regional comparison

This study focuses on Rwandan efforts to build a national innovation system. Further, it employs a regional and comparative perspective by contrasting the development in Rwanda with two other countries from the East African Community,[1] Kenya and Tanzania. The selection of these two countries is based on the cluster classification elaborated by the African Capacity Building Foundation where countries are classified based on their capacities in science, technology and innovation (ACBF 2017). All countries in the Community, except South Sudan for which no classification is provided, are classified as either high or medium in scales ranging from low to very high. The three countries are classified as having either medium (Kenya and Tanzania) or high (Rwanda) STI capacity. Thus, even though the East-African region consists of countries with quite different socio-economic realities, the three countries reflect fairly well the general level of STI capacity in the region.

Country profiles for the three countries on STI capacity and performance were constructed through a structured review of key policy documents and performance reports. The main data sources used include the African Innovation Outlook of 2014, the UNESCO Science report of 2016, the African Capacity Building Foundation report of 2017, as well as countries' reports from national offices in charge of STI. The collected data were used to build and compare macro-level country profiles for Rwanda, Kenya and Tanzania.

3.2. Rwanda case study

The regional macro-level comparison provides a backdrop for the in-depth case study of Rwanda. Empirical data were collected through a survey of STI personnel in Rwanda where the opinions of representatives of different stakeholders were solicited in semi-structured interviews. Categories of institutions included government institutions (ministries, public research agencies and policymaking agencies), academic and research institutions, private sector and research funding bodies. The criteria for selecting the institutions were that they have a mandate either to perform research or to regulate research in some form. The criteria for selecting the representatives of the institutions to interview were that they either were senior researchers and/or responsible for research management at the institutions and/or involved in setting institutional or national policies for STI.

The interviews were conducted using an interview guide with semi-structured questions. A draft of the interview guide was first tested in a pilot study and subsequently revised (Annex I). The interviews were conducted during the period of December 2017 to February 2018. 24 persons (Table 1) were interviewed, and each interview lasted for 30 min to 1 h. The interview guide had an introductory section with the purpose of the study and request for consent. Prior to each interview, interviewees granted their consent and interviews were conducted in the form of a conversation guided by 15 questions. These questions were focusing on stakeholders' understanding of innovation, perception on collaboration among stakeholders, funding, capacity

Table 1. Data acquisition and analysis.

Primary data collection: interviews	No. of interviewees	Secondary data acquisition	Data processing and analysis
Ministries (MINEDUC, MINICOM, MINECOFIN)	4	**Documents analysis**: Structured review of Policies, programmes, strategic plan, official reports.	- Qualitative data analysis: Word cloud analysis, keywords and parameters identification
Policy Making Public Agencies (REMA, RDB, NCST, NAEB)	6		- Categorization: Thematic analysis, synthetization of perceptions
Private Sector Federation	2		- Chart and graphs presentation
Research Funding Agency (Sida, DFID, IPAR)	3	**Databases exploration**: Data mining from UNESCO, WB, and ACBF database/bulletin.	
Research Public agency (NIRDA, RAB)	4		
University (UR)	5		

MINEDUC: Ministry of Education, MINICOM: Ministry of Trade and Industry, MINECOFIN: Ministry of Finance and Economic Planning, REMA: Rwanda Environmental Management Agency, RDB: Rwanda Development Board, NCST: National Commission for Science and Technology, NAEB: National Agriculture Export Development Board, Sida: Swedish International Development Agency, DFID: Department for International Development, IPAR: Institute for Policy Analysis and Research, NIRDA: National Industrial Research Development Agency, RAB: Rwanda Agriculture Board, UR: University of Rwanda.

building and policy and legal framework in support to innovation. Interview notes were taken during the discussion for further transcription, organization and analysis.

For analyzing the text, a checklist of parameters was established and keywords from the text were matched to parameters in the checklist. The parameters on the checklist included innovation categories (based on Oslo Manual, OECD 2018), NIS functions (based on Lundvall 2010 and Edquist and Hommen 2008) and key socio-economic sectors for innovation. In addition to these parameters, themes that reflect the perceptions on the construction process on NIS were extracted from the text and synthesized into a comprehensive text.

4. STI and NIS integration progress: regional efforts

The importance of STI for development in developing countries got its attention late compared to developed countries. Already in the 1960s, the first African countries mentioned STI consideration in their plans and programmes, but it was not among the priorities. At that time, the dominant paradigm of the modernization theory held that the capacities of the main knowledge producing institutions (universities and research institutes) in Africa were either insufficiently developed or too disconnected from society to be able to act as plausible sources of new technology (Arocena, Göransson, and Sutz 2014). It is not until the new millennium that the importance of STI has more concretely been addressed from an African perspective. The Lagos Plan of Action of 1980 served as a point of departure for the Lagos Consolidated Plan of Action of the early 2000s, which emphasized the promotion of STI as a driver for the envisaged socio-economic transformation for African countries. Efforts started to be invested in promoting the higher education system and building research capacity. Commitments were made in this attempt to promote STI, chief among them, to increase the R&D investment for African countries to 1% of GDP (Mugabe and Ambali 2005).

In addition to the increase of R&D investment, institutional development was prioritized as a means for better coordinating STI activities and to ensure collaboration among countries and individual institutions in Africa and globally through the New Partnership for African Development (NEPAD 2014). Regional Economic Communities (East Africa, West Africa, Southern Africa, North Africa and Central Africa) initiated other efforts. Particularly in the East African Region, the East African Science and Technology Commission (EASTECO) and the Inter-University Council for East African (IUCEA) were key regional organs that were put in place to coordinate and harmonize standards and facilitation for higher education and research as well as innovation in the region (African Union Commission 2014; UNESCO 2015). Different funding schemes to operationalize these organs were established as a means to support research and innovation in the East African region. Bio-Innovate-Africa programme is among the key initiatives, as well as the funding for African Centers of Excellence (ACE) by the World Bank through IUCEA and individual countries' governments in East and Southern Africa (IUCEA 2015; ICIPE 2017).

To ensure the alignment of STI with other development efforts, comprehensive agendas were put in place in conjunction with monitoring tools. Those include the STISAA and the STI indicators development initiative for Africa (Kahn 2008; African Union Commission 2014; New Partnership for African Development (NEPAD) 2014). In addition to this, operational frameworks to facilitate the integration of research in business communities were put in place. This can be observed through established partnerships between the IUCEA and the East African Business Council to foster joint research and innovation initiatives and inform potential areas for curricula improvement. The EAC Common Market Protocol of 2010 is also among the regional policy instruments that were put in place to ensure that market-led research aiming at technological development and technology adaptation in the society is conducted (UNESCO 2016). All these efforts, to some extent, contribute to individual countries' IS constructions as they shape the context of the system evolution.

Even though commitments on paper were strong, the progress made has been meagre when compared to the expectations expressed in visions and goals of the documents. Most African countries have developed their visions to align their development with the Millennium Development Goals, agenda 2063 as well as the current Sustainable Development Goals. However, the progress in using STI to deliver on those visions has not been satisfactory in many countries. There is still a great need for enhancing STI systems in different Regional Economic Communities of Africa. The East African region is seen as the best performing Regional Economic Community to the Agenda 2063 aspirations. This raises the societal expectations and puts high pressure on the building of efficient STI systems in East Africa (AUDA-NEPAD 2020), although there is a lack of skills, financial means and infrastructures, among other challenges. The progress in honouring commitments from individual countries has also been challenging; for instance, the R&D investment average at the continental level still looms at 0.5% of GDP with some countries at almost 0% of GDP (ACBF 2017).

The STI institutionalization has also been lagging behind other parts of the world; some African countries do not have sufficient organizations for the management of STI or policies to guide the promotion of STI. The NIS is expected to build on existing organization, interactive learning and innovation capabilities contributing to industrial

development. Considering the slow progress, it is hard to realize how interactions can be facilitated and how the NIS concept can be embraced. However, some countries have indeed made progress in promoting STI and setting the scene for accepting the NIS concept for ensuring the contribution of knowledge to the development of society. The East African region is among the parts of the African continent that have made some progress. The following section presents the system setting and STI integration performance of Rwanda in comparison to two of its neighbouring countries.

4.1. Progress in promoting STI in Rwanda, Tanzania and Kenya

Investment in STI is among the key strategic actions for making STI a tool for development and to ensure that the needed knowledge for societal development is being generated. The GDP composition of a nation may give a general picture of how R&D is making a difference in national economic development. Countries shifting from a natural resources-based development to a knowledge-based development show a higher rate of technological development, reflected in the progress made by its industrial sector (Freeman 1995). This does not seem to be the case for the East African Region, even though efforts are being made. The countries selected for this study have small differences in their GDP composition, with the service sector dominating in all countries followed by the agriculture sector. The industry sector is still lagging behind in Rwanda compared to the other countries, even though it is still relatively low also in the other countries compared to the current technological and products' demand in the region (UNESCO 2016). The R&D expenditure as a measure in effort in knowledge and technology production is still low compared to the commitment of 1% share of the GDP, especially for Rwanda and Tanzania, which are still below the continental average of 0.5% (ACBF 2017). Table 2 shows the countries' R&D expenditure per capita, per researchers and by sector of performance.

In relative terms, Rwanda spends less than half and less than a quarter of what Tanzania and Kenya respectively spend on R&D as a share of GDP. If we look at R&D expenditure by sector of performance, we can notice considerable differences between the countries, reflecting disparities in policies for knowledge generation. In Rwanda, almost a third of all R&D is carried out in the non-profit sector (Table 2). The corresponding figure for Kenya is 12% and virtually non-existent for Tanzania. In all three countries, Higher Education is a prominent performer of R&D, accounting for as much as 86% in Tanzania and close to 50% in Rwanda. In these two countries, the main R&D performer in industrialized countries, the business sector, is not an actor at all, whereas Kenya has seen the contribution of the business sector climb to 8.66% of

Table 2. R&D Expenditure (PPP$ and %).

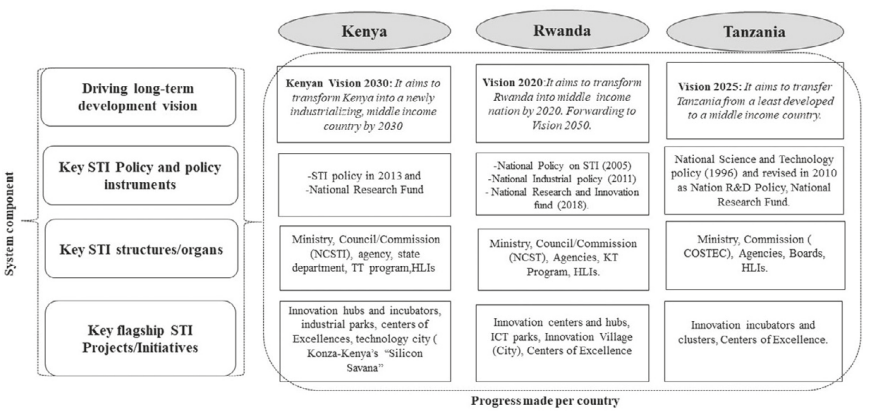
	GERD, 2013			R&D Expenditure by Sector of Performance (%), 2013			
Country	GERD (% GDP)	GERD Per Capita (%)	GERD (000s) per Researcher (HC)	Business	GVT	H. Educ.	Private Non Profit
Kenya	0.79	19.8	62	8.66	40.64	39.05	11.65
Rwanda*	0.17	2.5	56	0	21.22	49.11	29.67
Tanzania	0.38	7.7	110	0	13.75	86.25	0

Source: UNESCO 2016, *Data for Rwanda are estimates calculated using R&D survey data (UNESCO 2015).

total R&D expenditure in 2013. The situation with low levels of resources devoted to R&D and the absence of major actors in the NIS is further exacerbated by the fact that much of the funding is appropriated from abroad in the form of Official Development Aid (ODA) and other international sources. Foreign funding contributes about 69, 47 and 42% for Rwanda, Kenya and Tanzania respectively (UNESCO 2016). This shows the need for all the countries to develop strategies to build internal funding mechanisms, shy away from the high reliance on foreign funding and instead develop collaborative mechanisms with external research communities built on mutual contributions.

4.2. Institutional and organization development in Rwanda, Tanzania and Kenya

Among the key components of innovation systems are institutions, both formal and informal, as well as aligned working environment characterized by policies and legal frameworks (Edquist and Hommen 2008). For emerging national innovation systems, the setting up of organizations and institutions for facilitating the production, acquisition, diffusion, transfer and use of economically valuable knowledge are among the key steps. Knowledge infrastructures development is important as well as human capital development. To understand the process of NIS construction in developing context like the East African region context, it is relevant to look at how countries have developed their long-term development visions and how they are setting up systems to make STI as a matter for achieving those envisioned long-term development goals. This can be examined by looking at the progress in developing institutions and policy instruments as well as emerging initiatives as a way of starting the system move. Figure 1 shows the progress made by each of the selected countries in the above-mentioned issues.



STI: Science, Technology and Innovation, NCSTI: National Commission for Science, Technology and Innovation, TT: Technology Transfer, HLIs: Higher Learning Institutions, NCST: National Commission for Science and Technology, KT: Knowledge Transfer, ICT: Information Communication Technology, R&D: Research and Development, COSTEC: Commission for Science and Technology.

Figure 1. Progress in national STI and R&D organizational development. Source: Authors' own compilation based on United Republic of Tanzania 1999; Republic of Kenya 2007; World Bank 2008; Republic of Rwanda 2012; UNESCO 2016.

As seen in Figure 1, Rwanda has a highly ambitious vision 2020. That country also exhibits a consistently high and positive trend in GDP growth in recent years (UNESCO 2015; IMF 2019) despite exhibiting the lowest investment level in R&D of the three countries. Partly, this can be explained by the fact that the current sustained economic growth is not so much relying on knowledge and technologies produced locally but rather on the importation of technology. However, the reliance on technology importation does not, in most cases, offer sustainable development solutions (Juma 2016). With the current R&D investment for Rwanda, it is hard to imagine the achievement of the envisioned knowledge-based economy and economic transformation, unless strategic measures in R&D funding can be developed or collaborative mechanisms that stimulate active learning can be fostered, raising internal research and technological competencies. The worrying situation is not only for Rwanda, the other countries in this study are also concerned as well, considering that they all base their R&D funding on foreign funds; as shown in Table 2, only Kenya has taken steps to involve the business sector in investing and performing R&D.

5. National innovation system in Rwanda: empirical evidence on the construction process

5.1. The emergence of the NIS concept in Rwanda and its integration progress

The survey of STI personnel in Rwanda reveals that the NIS concept in Rwanda is not uniformly understood by all stakeholders. The general low level of awareness of the concept among some stakeholders makes it harder for the actors in the innovation system to work in harmony. Without a clear understanding of the inner workings of the innovation system, the identification and alignment of inter and intra-institutional responsibilities become haphazard at best (Chaminade, Lundvall, and Haneef 2018; Fagerberg, Bengt-Åke, and Srholec 2018). Academic and research institutions in Rwanda appear to understand the concept fairly well whereas private and government institutions have a relatively low level of understanding of the concept. Considering the Rwandan ambition of fairly rapidly becoming a knowledge-based economy, efforts are being invested in establishing institutions and organizations to promote higher education and research, but the interactions among institutions that are emerging and the rest of the society are still challenging. Respondents recognized that a strong education system can help in building the Rwandan NIS as this can be the source of qualified graduates who can serve in the business sector as well as the society at large. In the interviews, the performance of problem-based research was highlighted as a key driver for constructing a NIS but the Rwandan research environment shows a low level of interaction among researchers and research end-users. This makes research that is being conducted unresponsive to demands of the society.

> *-Does the system exist? I know that there are strategic policies that drive plans and actions considering innovations for improvement. Innovation is reflected in most of the policy documents and innovative ways of doing things are encouraged. If the system is to be established then, it needs to be well understood and I think that it needs to take reference from where it succeeded (Senior policymaker).*

-Our organization is not much familiar with the NIS, however, we recognize the need for research to find solutions that match with the national development pace, like in the agriculture sector we need solutions to increase the production that meets the demand (Private Sector Federation Representative).

Further, the institutional setting is considered as a key component for the NIS development (Högselius 2005; Chaminade and Lundvall 2019). The survey shows that vital institutions indeed are being established to make research more relevant to society and to ensure that the knowledge that is being produced is put to good use. Critical institutions like the National Council for Science and Technology and the National Industrial Research Development Agency have been established. However, the collaboration among institutions is still low and this slows the Rwandan NIS construction process.

Several respondents of the survey point to the very low level of collaboration between academic/research institutions and the private sector. The lack of interactions may also be linked to poor coordination and facilitation from public institutions that are mandated to do that. This may be resulting from the weak institutional framework and lack of clear policy frameworks, as highlighted by respondents. Institutions are there, but operate in silos.

The current stage in the construction process from the narrow perspective shows low interactions in STI organization and R&D performance. The narrow perspective focuses on the organization of STI and R&D performance and it is at the centre of the NIS maturity and performance (Cassiolato et al. 2006). With the observed low interactions, the current status on the Rwandan NIS seems to be at the early stage although promising based on the commitment and trends in activities aiming at establishing an operational NIS. The broader perspective that consists of the overall operational environment seems to be more developed as there is a high political will expressed in policy documents and leadership commitments. The high interest from the society also expresses a promising social and cultural acceptance of innovations, which is a challenge in some places in the NIS construction process, particularly in developing countries. The coordination and absorptive capacity are among the major challenges from a broader perspective. Figure 2 shows the overall map of the Rwanda NIS in both narrow and broader perspectives based on interviews and policy document data.

5.2. Awareness of the concept of innovation and views on its economic impact in Rwanda

Contrary to the rather low understanding of the notion of the NIS, the respondents exhibited a high level of *awareness* of the concept of innovation; however, their views and definitions of innovation varied across stakeholders' categories. Despite this variation in views, perceptions on the end results from innovations remain similar as all interviewed people acknowledged that innovations aim at addressing community needs. Actors from the education sector view innovation as the application of new knowledge or value addition to the existing knowledge for addressing the community needs and they recognize that the knowledge is to be generated from research and education. However, a few mentioned experience and exposure to be the source of needed knowledge for innovation. This reflects the status of incremental innovation dominating in developing countries which are mainly results of utilization of imported technologies

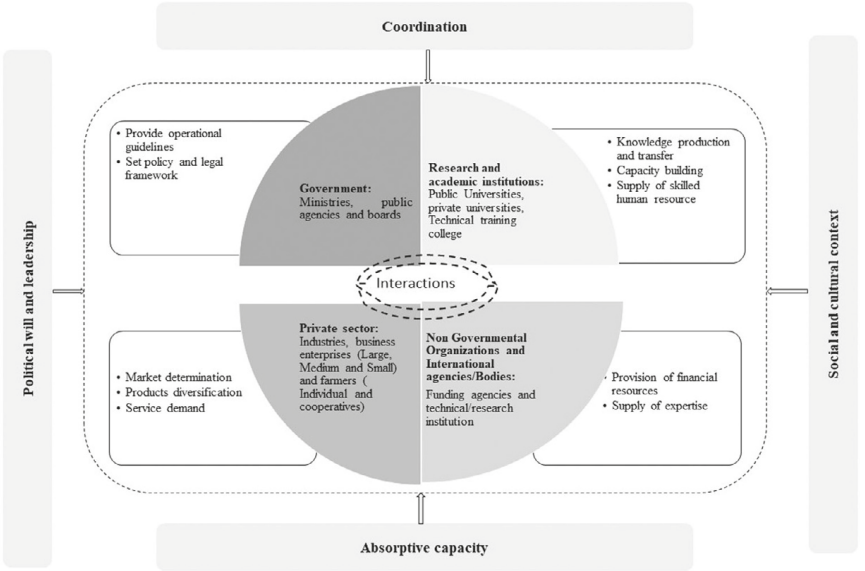


Figure 2. General layout of the Rwandan NIS. Source: By authors, 2018.

with active learning as a technology adoption approach (González-Pernía, Parrilli, and Peña-Legazkue 2015). The public/government and private sectors perceive innovation as any new thing that is done differently and have a positive impact. This view is not much different from the higher education perspective, although both these sectors view innovation as an end product in itself without considering the process and key stimulating factors.

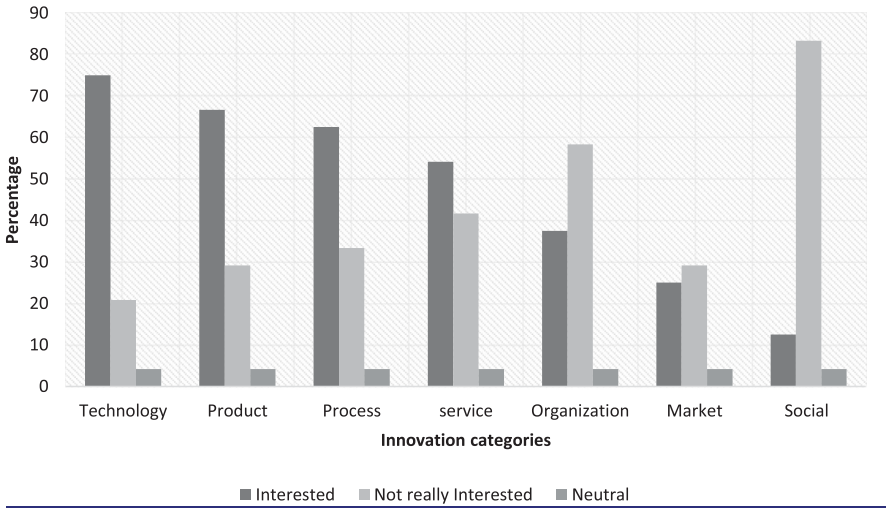
> *-It is hard to define innovation as different organizations may have their own definition depending on their focus. This is driven by agendas in place and discussion. In Rwanda, it is hard because there is no public discussion on innovation and the understanding of innovation among stakeholders is still problematic (Funding agency).*

> *-Innovation is the application of knowledge or research outputs to meet the market demand. They can be a technology or a new market. However, we need to differentiate innovation and invention even though both have commonalities (University researcher).*

> *-Innovation in PSF is viewed as any solution to the relevant problem in the society that helps in creating new jobs, new market and transform the livelihood in the society (PSF Representative).*

The interest expressed by the stakeholders in innovation (Table 3) ultimately defines their perception of the importance of innovation to national economic development. Stakeholders' interest in innovation categories (adapted from Oslo manual of 2018) was high with a variation from technology innovations to social innovations. Technology innovations were viewed by most of the stakeholders as the most important category and much needed in the Rwandan society, followed by product, process, service, organization, market and social innovations respectively (Table 3). Technology and product

Table 3. Stakeholder interest in innovation categories.



Source: Survey by the authors, 2018.

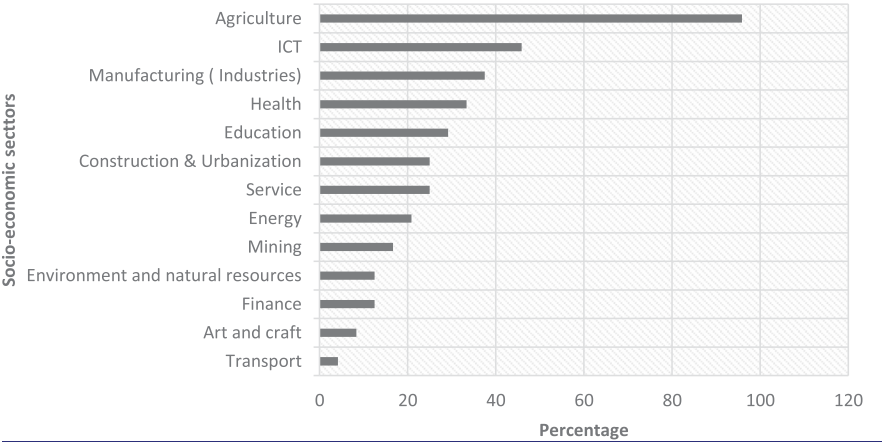
innovations were most commonly indicated as of high interest for respondents from all sectors. However, service and organization innovations were of high interest in education and public/government sectors whereas the private sector is much interested in market and technology innovations.

5.3. Potential socio-economic sectors for innovation in Rwanda

Based on the demand from the Rwandan society, there is a wide range of possible innovations even though resources are limited. The current demand in the Rwandan society calls for innovation in different socio-economic sectors to achieve the expected socio-economic transformation. Respondents to the survey have varying views on the potential for innovation in different sectors in Rwanda where increased innovation capabilities can lead to considerable industrial development and development of society in general. The agriculture sector scores highest among potential and promising sectors. Other key sectors including ICT, industry (manufacturing), health, education, service and construction and urbanization are considered to have potential for innovation (Table 4). This does not exclude other sectors to have innovation potential but those are key sectors perceived to be promising, based on current demand, government priorities and possibilities for investment and resources mobilization. The list appears to be long, and for realizable impact, priorities need to be set.

Priority setting is one of the best practices in building internal capabilities, especially in the case of scarce resources (Dosso, Kleibrink, and Matusiak 2018). The stakeholders' views on potential socio-economic sectors might pave the way for priority setting in building innovation systems in key sectors which can ultimately contribute to the overall NIS performance. This might be also a tool for local and regional innovation systems development, which can enhance industrial development in specific regions

Table 4. Perceptions on the potential for innovation in socio-economic sectors.



Source: Survey by authors, 2018.

and sectors depending on existing potential and their efficient exploitation. The understanding of innovation propensity in potential socio-economic sectors plays an important role in resources allocation and specialization in tools and mechanisms for interaction and learning process (Freeman 1995; Leydesdorff et al. 2019). The observed high potential in agriculture and ICT sectors, if well exploited, can influence other sectors as both are comprehensive sectors covering a wide range of actors and different localities across the country.

5.4. Systemic interactions: innovation pathways and stakeholders' linkage

The process of innovation *dissemination* remains unclear to many stakeholders in Rwandan institutions and is perceived as challenging, even hard to realize. Dissemination in this context entails bringing the innovation to end-users, either in the form of a commercial undertaking or as a social innovation transferred directly to the users, e.g. improved agricultural farming techniques. Only a few representatives of institutions stated that substantial steps in dissemination have been taken. Major reasons for this low dissemination ability identified by the respondents include the lack of clear dissemination framework, lack of coordination at the national level and within institutions, lack of flexible systems that allow dynamism among stakeholders, lack of skills for better profiling innovations to be disseminated and lack of financial means as well as lack of a supportive and receptive mindset for innovation for end-users. In addition to these major reasons, poor information sharing and lack of knowledge commercialization strategies, as well as low skills in Intellectual Properties management are recognized by the interviewees as limiting factors for innovation dissemination.

> *-It remains unclear as to how innovation generation and dissemination are coordinated, as sources of innovation are not well mapped out and some potential innovators don't even know that they have that potential. At the national level, there are gaps particularly due to*

the lack of frameworks to coordinate innovation processes. The conflict of interest among stakeholders is observed as one of the hindering factors for innovation development and dissemination (Senior Policy Maker).

-Innovation development and dissemination is still challenging in Rwanda, as many stakeholders consider technology/solution importation as innovation and most reliable compared to local solutions. The mindset in relying on imported solutions and lack of financial means are key hindering factors for innovation dissemination. However, the negative competition and rivality among innovators can't be negligated as well (Senior STI Manager).

Although innovation dissemination is still very low in many institutions, it was recognized in institutions where dissemination actually is occurring (e.g. the Institute for Policy Analysis and Research (IPAR) and Rwanda Agriculture Board (RAB)) that public dialogue, innovation platforms, community innovation centres, workshops, seminars and conferences are major pathways for dissemination. However, it was generally highlighted by most stakeholders that it is important to set platforms for stakeholders' interactions, varying from intra to inter- institutional collaborations. Among the ways to do that include establishment of innovation uptake offices, establishing stakeholders/professional networks, creation of incubators and setting proper communication channels as well enabling a business environment that stimulates commercialization of knowledge. Integrated multidisciplinary approaches for innovation dissemination are encouraged for research institutions whereas public dialogues and market linkage are considered by the respondents as the best approaches to link researchers, public sector and private sector respectively.

To increase dissemination capacity, the importance of collaboration among stakeholders was highlighted in aspects related to capacity building, financial resources mobilization and infrastructure sharing. Most of the respondents stated that their institutions were engaged in collaboration in different forms including both formalized and non-formal collaborations. Formalized collaborations include collaborations under contract agreements, loans, MoUs and joint projects. Stakeholder collaborations include universities, ministries, government agencies, research institutions, industries, business companies, community-based organizations, local NGOs, international NGOs, UN agencies and international funding bodies like USAID, DFID, Sida, AfDB and WB. Figure 3 shows the current status and future perspective of origin and dissemination of innovations, considering key players as well as challenges they are facing in the process.

A low level of collaboration among local institutions was observed compared to collaboration with international and regional institutions. Collaborations among public institutions are very low and most of the actors claim this to be the root cause of the low performance of the entire systems as this in many cases results in duplications of efforts. Collaboration between universities and local industries/private sector was judged to be almost non-existent and even in cases where collaborations have been initiated by government push, they did not materialize and did not result in any positive impact or sustained initiative contributing to innovation development.

The development and dissemination of new knowledge are key for the construction process of the innovation system. The source of innovation and pathways for dissemination as well as actors engagement is crucial in the construction process and requires preparedness as well as a welcoming environment (Alkemade, Kleinschmidt, and Hekkert

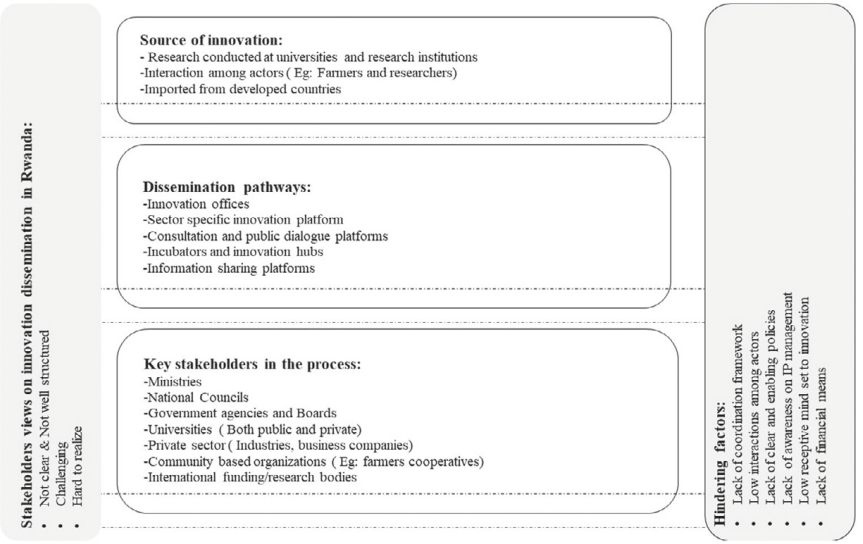


Figure 3. Innovation emergence and dissemination pathways as well as associated challenges. Source: Survey by the authors, 2018.

2007; Fagerberg, Fosaas, and Sapprasert 2012). As interview results showed, sources of innovation, as well as pathways, are unclear to actors. That coupled with the low receptive mindset of end users are among the key hindering factors. As suggested by Chaminade and Lundvall (2019) and Kraemer-Mbula and Wamae (2010), clear organizational structures and coherent mandates are major factors to build synergies in the knowledge production and dissemination process. This also needs to be accompanied by attributes and values such as trust and loyalty among actors. This can be facilitated by enhancing open debates on innovation and policy dialogues among actors.

5.5. Research and innovation policy and governance framework

Research and innovation policy and governance frameworks in Rwanda are perceived by stakeholders as relatively supportive to research and innovation development, albeit with limited enabling capacity as there are no recognizable incentive schemes for innovators and researchers. Policies for STI are perceived as well formulated as they are considered to be aligned with the government agenda and development plans. But this does not exclude the observed duplications and overlaps in policies which results in low implementation and waste of resources.

Even though there is a National Science, Technology and Innovation policy put in place in 2006, it is not yet accompanied by other policy instruments, which are still in the pipeline or in future plans as acknowledged by NCST. Development of research and innovation policies at intuitional levels is still very low as most academic and research institutions as well as public institutions do not have institutional research policies but rather have research strategies in place. Few of them have research units to

manage research activities; only academic and research institutions have made any progress in establishing research units. As pointed out by the representative of the Private Sector Federation (PSF), the Rwandan private sector shows a low interest in research and this explains the lack of R&D units in almost all industries in Rwanda. However, the PSF is establishing a research unit on market research. This newly started unit has a very low number of researchers; it relies on outsourcing consultants but has a long-term vision of hiring permanent researchers in different disciplines of research that are pertinent to the Rwandan private sector.

Despite the effort devoted to new structures for research management, innovation management is still lagging behind in matters related to policy frameworks. There is no institution in Rwanda with a specific innovation policy and few have offices that focus on innovation matters only; those that do are academic and research institutions. Examples are the University of Rwanda and the National Industrial Research Development Agency. In most other institutions, research and innovation are managed under research units and research strategies cover innovation matters when it comes to policies.

Despite the existence of national policies and laws – such as the Intellectual Property Law – as well as institutions performing research and innovation, there is a number of management challenges that deserve attention. Among these are the lack of policy implementation mechanisms and tools, lack of skilled human capital for policy formulation and implementation, lack of awareness on the existence of some policies and laws, duplication and overlaps among policies, instability and lack of flexibility in policies and disconnect among policy-makers and implementers. The lack of awareness on policies and law coupled with a lack of implementation mechanisms were key challenges mentioned by all respondents. Research and academic institutions perceived policies to have overlaps and duplications as well as being unstable without allowing time for implementation and assessing their impact.

> *-There are some policies in place and law (STI policy, IP law, …) but they present some challenges related to duplication and overlaps in their scope. Their implementation is problematic and deserves attention from policymakers. National policies should be accompanied by institutional policies for effective implementation at different levels. Although, this is not observed in many research and academic institutions when it comes to innovation policy. A conducive environment for policy implementation needs to be in place as well with skilled human resources (University Researcher).*

> *-In Rwanda, policies, regulations and laws are in place but people are not aware of them and their implementation is still low. Innovators should be sensitized about the existence of the IP law and how beneficial it can be to protect their IP as most of the people in the Rwandan context are not aware of the IP issues (Innovation Manager at University.)*

Supporting the formation and reconfiguration of inter-organization networks is one of the important roles of innovation policy. In addition to this, STI policies are expected to ensure that there are appropriate institutional frameworks to support innovation and the innovation process itself (Chaminade and Lundvall 2019). With the highlighted instability and confusion in STI policies in Rwanda, it may require considerable efforts in stabilizing policies through the enhancement of policy-making processes that involve key actors in the system. This would contribute to overcoming the identified challenge of

policy implementation and coordination. This can also contribute to building long term relationships among actors involved in the process and a departure from crisis management interventions. Such relationships are crucial for the success of an innovation system (Lundvall 2007; Clark 2002).

6. Concluding remarks: insights and prospects for the Rwandan NIS construction process

It is a premise of this paper that the National Innovation System as a model of innovation needs a thorough scrutiny before its integration in a developing countries' context (Lundvall 2007; Kraemer-Mbula and Wamae 2010). The adoption and integration of NIS need to take into account contextual realities that differ between countries and levels of economic activities. The ongoing debate on adoption and contextualization of NIS in developing countries has to consider dynamics in organizational structure, knowledge production capacity as well as end users absorptive capacity. The Rwandan case confirms a high need for enhanced interactive learning with a balanced use of modes of learning. The role of innovation policies and understanding of innovation process are other fundamental aspects for the contextualization of the NIS model. The integration of NIS appears to be progressive process with different stages that include different milestones. There is an ongoing debate on how to measure these stages in the integration process. However, it is important to ensure coherence between patterns of the narrow and broader perspectives of the NIS in the construction process.

For Rwanda, the construction process of the National Innovation System exhibits some characteristics of the ideal NIS prescribed in the literature. However, it is evident that there still is a lack of understanding of the concept itself among the stakeholders. The efforts towards NIS construction in Rwanda are oriented to the narrow NIS with a strong interest in increasing R&D investment, STI capacity building and infrastructure development. R&D-based knowledge is considered to be the most reliable source of innovation. However, it might be wise to consider other modes of knowledge acquisition and accumulation like 'learning by doing' and ' learning by using' in the construction process as suggested by Lundvall (1998) and González-Pernía, Parrilli, and Peña-Legazkue (2015). This of course requires building capacity and capabilities; both dynamic and absorptive capabilities are imperative in this case. The enhancement of the higher education system and strong collaborations as well as proper organizational structures can be among the option to build such capabilities.

This leads to a further premise of this paper, which is that awareness among the stakeholders of the NIS concept and its economic impact is vital for understanding ways for building a system that promotes innovation as a tool for economic growth. This point to the broader NIS that needs to be consistent with the narrow NIS for a sustainable comprehensive NIS. Supportive political environment, socio-cultural support systems and a conducive business environment are major components to focus on in the broader NIS construction process, as observed in the Rwandan case. The level of understanding of the concept and its associated element has a considerable impact on the broad NIS construction. In addition to this, the effect of geographical proximities and regional integration needs to be considered for possible effects on

economic growth. In the context of small countries like Rwanda, a selective approach in the system construction process can be an option in linking transnational innovation system and local innovation systems (Shafaeddin 2000). This should be associated with coherent policies and policy instruments that allow for collaboration and synergetic actions among stakeholders.

Based on the standard theoretical provisions, the NIS construction process in Rwanda shows promising progress. However, there is still a lack of focus on ensuring interactions among actors and synergies among institutions. It may take time to build an effective NIS in Rwanda, as in many other developing countries, but it is feasible if the concept is well understood by the government agencies that are mandated to promote STI. It is clear from the survey that government and higher education institutions are the almost exclusive performers of STI in Rwanda. However, constructing a dynamic NIS also requires the involvement of industry as the main user of knowledge and technologies produced from R&D as well as a potential investor in R&D. This is particularly relevant for the development of the agro-business sector, which holds a high potential for innovation activities and industrial development.

Rwanda has made a good progress in accepting the NIS concept compared to its neighbouring countries in the region. This is particularly so in matters related to STI in policies and national development plan as well as institutional development. However, Rwanda is still lagging behind in matters related to R&D funding compared to the two other countries in the region used in this study, Kenya and Tanzania. This indicates the need for Rwanda to set up mechanisms for research fund mobilization as well as for reconsidering national funding priorities of R&D in order to achieve the aspired knowledge-based economy that is reflected in the national development plans and programmes. Moreover, the country exhibits a lack of research capacity in both infrastructure and human resources. It remains a challenge to enhance interaction with industries and other end-users of innovations. Incubators are identified as the main instrument for maturing innovative ideas, but it is still a challenge to proceed from incubation to commercialization and utilization in society. This would appear to be connected to the lack of collaboration among actors; hence, the enhancement of collaborative frameworks is key in Rwanda's NIS ongoing construction process, and by extension, in the building up of innovation capabilities and industrial development.

Note

1. Encompasses Burundi, Kenya, Rwanda South Sudan, Tanzania and Uganda.

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Disclosure statement

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Annex I. Interview guide for the survey with STI personnel in Rwanda.

Initiating questions/Points of discussion	
I.	Are you familiar with the National Innovation System (NIS) concept in your institution? If Yes, what are your views on it?
II.	What do you consider as innovation and what are forms of innovation that your institution is interested in?
III.	What is your view on how innovations emerge and are disseminated?
IV.	What are your views on the role of Innovation in achieving the national economic development goals?
V.	How do you view the policy and legal frameworks in promoting innovation for development?
VI.	What socio-economic sectors innovation can contribute the greatest to economic transformation or development goals?
VII.	With whom does your institution work with for research and innovation matters?
VIII.	How is research and innovation managed in your institution?
IX.	IX. How does your institution promote the move from research to innovation?
X.	What are funding mechanisms for Research and Development (R&D) in your institution?
XI.	What are mechanisms for funding Innovation activities in your institution?
XII.	How does your institution facilitate (get involved in or support or promote) the move from Innovation to entrepreneurship?
XIII.	What factors do you think are hindering or slowing the move from innovation to entrepreneurship?
XIV.	What are mechanisms for capacity and competence development for innovation available in your institution?
XV.	What is one strategy that you think could boost research and innovation uptake in Rwanda?
XVI.	Concluding statement: Is there anything you wish to be done in the future to improve the performance of your institution in Research and Innovation promotion and Rwandan NIS development in general?

Paper III

Article

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Emergence of an agriculture innovation system in Rwanda: Stakeholders and policies as points of departure

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Abstract
The concept of an innovation system is used to understand how innovation contributes to economic growth. However, innovation systems do not evolve evenly in different parts of the world. This paper contributes to the ongoing debate on the emergence of innovation systems in the context of developing countries. It uses the Rwandan case, where agriculture is a dominant socio-economic sector with high innovation potential. It explores how stakeholder interactions and policies contribute to the emergence of an agriculture innovation system in Rwanda. Based on interviews with relevant stakeholders and a review of policy documents, the authors use the Triple Helix model to analyze interactions among stakeholders. They also explore the policymaking approaches used to formulate policy instruments and how these policy instruments contribute to the promotion of innovation activities. The study shows that stakeholder interactions and policies are important factors in providing the preconditions for innovation performance. There is a clear expression of interest and commitment to promote innovation activities in different policy instruments. Nevertheless, further strategic issues, such as evidence-based policymaking, institutional capacity building, better allocation of resources and platforms for promoting collaboration among stakeholders, need to be improved in order to build a functioning agriculture innovation system in Rwanda.

Keywords
Agriculture, innovation policy, innovation systems, Rwanda, stakeholder interaction, Triple Helix

Innovation can drive growth and create jobs, and happens in the least developed countries as well as in the most developed. Innovation is not only the conception of a new product; it is also a complex phenomenon involving the production, diffusion and translation of knowledge into new products or new processes that address societal problems. The innovation process starts with the conception of a new idea or a thought which is converted into a tangible product, process or service that can be exploited commercially to address technical, economic or social needs and problems (OECD/Eurostat, 2018). However, innovation processes cannot be decomposed into several isolated phases that take place in a strictly proceeding sequence. It is a systemic process that involves complex and interactive learning activities. Innovation system has become a popular analytical framework to organize the innovation process to achieve the desired socio-economic outcomes (Hall et al., 2005).

Traditionally, an innovation system can be described as the set of institutions that jointly and individually contribute to the development and diffusion of new technologies and which provide the framework within which the government formulates and implements policies to influence the innovation process (Metcalfe, 1995). In particular, innovation systems are defined as social systems made by social actors, namely *institutions* and *organizations* (Johnson, 1997). Institutions constitute sets of habits, practices and rules or laws that regulate and facilitate the relationships and interactions of participating actors, while

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organizations are entities such as enterprises, research institutes, farmers' cooperatives and governmental and non-governmental bodies (Edquist and Hommen, 2008; Högselius, 2005; Lundvall, 2010).

The innovation system framework emphasizes the importance of studying innovation as a process in which knowledge is accumulated, diffused and applied by heterogeneous agents through interactions that are shaped by social and economic institutions. The nature of social systems is that they are *dynamic* and *open* to external interactions (Lundvall, 1992). Yet, innovation systems must have a certain degree of internal coherence that must be higher than the respective degree of the external environment. Given that social systems are influenced in an irreversible way by the external reality, innovation systems are argued to be *path-dependent*; that is, they are the result of the local socio-economic history (Johnson, 1997).

Understanding the linkages among stakeholders of the innovation process and designing policy instruments to facilitate these linkages are also argued to be critical to improve the innovative performance of a country (Lundvall, 1992; Nelson, 1993). Policies, both innovation policies and other supporting public policies, influence behaviors and practices of actors in the innovation system. Thus, when designing effective policies, it is important to take into account the behaviors and practices that are likely to be affected by the policies (Mytelka and Smith, 2002). However, the all-encompassing nature of innovation systems often poses a challenge to policymakers to essentially understand the process of knowledge production and diffusion between different stakeholders (e.g., between universities and firms or between firms). To a certain extent the Triple Helix model (THM) has emerged to address these complex relations among the actors in the innovation system by streamlining the theoretical focus on the three salient actors: universities, firms and government (Etzkowitz and Dzisah, 2008; Etzkowitz and Leydesdorff, 2000). The THM helps us to explore two major dimensions: university–industry relationships and policymaking. Both dimensions are, as a matter of fact, critical for establishing a functioning innovation system, and thus for its ensuing performance.

Innovation systems have been used as a framework to strengthen innovation at different levels (national, regional and sectoral) (Högselius, 2005). Similarly, the THM can also be used as an appropriate tool for analyzing interaction at different levels, such as sectoral innovation systems (Leydesdorff and Fritsch, 2006). Sectoral innovation systems can be based on a specific sector of the economy or a specific technology or product, and comprise specialized organizations and institutions in a specific sector that interact to enhance innovation performance for its socio-economic impact on national development (Coenen, 2006; Högselius, 2005).

These approaches make "innovation" more explicable and measurable, and eventually rationalize the initiation of specific policy instruments, such as those intended to enhance collaboration among different actors at the regional level through innovative clusters and incubators (Isaksen and Asheim, 2002). Moreover, some innovation policy reforms are designed to boost the entrepreneurial and innovative potential of universities and firms (Etzkowitz, 2013). Furthermore, some innovation policies are introduced to enhance the innovation potential of particular sectors, such as agriculture, health, finance, ICT biotechnology, manufacturing, energy, etc. (Juma, 2016; Malerba, 2007).

As discussed by Schut et al. (2015) and Yongabo and Göransson (2020), agriculture is one of the critical sectors with high innovation potential for most developing countries. This has increased interest in understanding the dynamics of technology and innovation in the agriculture sector. The agricultural innovation system (AIS) could be defined as the application of innovation systems perspectives about agricultural research and technological change to the study of how society generates, disseminates and utilizes knowledge to respond to complex problems in the agriculture sector (Schut et al., 2015; Spielman et al., 2009). The AIS approach looks at multiple conditions and relationships that promote innovation in agriculture. As does the broader innovation system, the AIS takes into account the facilitation of the application of knowledge and associated policy actions. The efficiency of the AIS and associated policy actions are likely to be dependent on public policy frameworks and governance in the sector (Clark, 2002).

Due to the prominent role of the agriculture sector in most developing countries as a source of income, employment and food security, a focus on "improving the conditions for agriculture" has been a popular point of departure for many scholars to study the AIS and development (Hall et al., 2005; Juma, 2015; Schut et al., 2015). Over the years, the AIS has moved from a concept to a subdiscipline with principles of analysis and action (Klerkx et al., 2012).

In Rwanda, agriculture is one of the most promising sectors for innovation, dominating societal and economic lives. Around 69% of the total population in Rwanda are employed in the sector, of whom 80.2% live in rural areas (NISR, 2018). Despite some improvements, the agriculture sector in Rwanda faces challenges due both to natural causes (such as climate change, diseases and pests) and to human-made problems, such as land degradation, financing and youth engagement in farming (Gahakwa et al., 2014; MINAGRI, 2018b). One particular issue for Rwanda, especially within the scope of this study, is the lack of collaborative partnerships and interactions among the key stakeholders in the agriculture sector to address these challenges. A salient issue in relation to collaboration is the utilization of available research capacity at research institutes and universities to provide innovative solutions to

pertinent problems for farmers (see Bizoza and de Graaff, 2012; Ngaboyisonga et al., 2014).

In this paper we focus on efforts to provide conditions for innovation as a means to build the Rwandan AIS. The paper aims to assess *how stakeholders' interactions and policies contribute to the emergence of the Rwandan agriculture innovation system*. We explore the role of stakeholders and the associated institutional set-up in fostering innovation and how policies and policy instruments contribute to the emergence of or enable the formation of the AIS.

We use the THM to map out key stakeholders and assess how they interact to perform their roles and functions to foster innovation. We also assess the policymaking approaches that are used to design policies and policy instruments and how they support innovation activities. It is our contention that policies and stakeholder' interactions are key factors that define preconditions for the innovation process in emerging innovation systems. However, the way policies are made and norms and institutional set-ups for stakeholders' interactions are context-dependent.

After this brief introduction, we present the context of the study, our literature review and the methodological framework used to address our research question. We present empirical findings on stakeholders' roles and their interactions, followed by an analysis of how institutional set-ups, policy instruments and policymaking approaches contribute to facilitate the emergence of an AIS in Rwanda. We conclude with a discussion and summary of the key findings and of how this study contributes to the ongoing debate in innovation studies about factors and conditions for the emergence of innovation systems in developing countries, particularly African countries. Despite a number of policy or consultancy reports, this study is one of the first academic works focusing on an AIS in Rwanda. Our purpose is not to provide a final response to this debate; it is rather to present our findings to emphasize the importance and relevance of the AIS for Rwanda while also showing the hurdles of innovation policymaking within the agriculture sector.

We aim to increase awareness among all stakeholders that establishing a well-functioning innovation system does not happen instantly, requiring not only capacity building among individual stakeholders but a more systemic approach that encourages public–private partnership—for example, the intensification of university–industry relations within the spirit of the THM. Our focus on the agriculture sector should not mislead readers; we believe our findings have relevance for other sectors in Rwanda. Agriculture is not an isolated sector, but rather is connected to several others, including industry, service, ICT, energy, finance and health. Furthermore, Rwanda is participating in several international and regional initiatives and collaborative projects (e.g., within the East African Community), and, by presenting the situation in Rwanda, we expect our study to provide relevant insights to such partnerships.

Setting the stage: Overview of the Rwandan agriculture sector

The Rwandan economy has experienced continuous growth over the past decade, with an average GDP growth of around 7% for the period 2007–19 (NISR, 2019). This economic growth is a result of joint efforts in different sectors of the economy led by the service, agriculture and industry sectors. The agriculture sector contributes significantly to the national GDP (Figure 1), although its contribution has been varying, with a slight decrease due to climatic conditions (heavy rains and drought) and soil fertility decline, as well as crop pests and diseases that have affected production over time. The sector also contributes to the Rwandan performance on the international market through the increase of exports (Ministry of Trade and Industry, 2013; NISR, 2015, 2019; MINECOFIN, 2012). Besides its overall contribution to national economic growth, agriculture contributes to the development of other socio-economic sectors, including industry, business, health and community livelihood improvement in general. This is done through the provision of raw materials for agro-processing, enabling access to sufficient, nutritious and healthy food and offering business and entrepreneurial opportunities at different stages of the value chain.

Additionally, the agriculture sector offers jobs and further job creation opportunities for Rwandans. As noted above, currently the sector employs around 69% of the total population in Rwanda, of which 80.2% live in rural areas. About 86.5% of non-educated people and 75.7% of people with only primary education are employed in the sector. However, less than 8% of highly educated people (7.9% with a university degree) participate in the agriculture sector (NISR, 2018), and this may have limited the opportunity for interactive learning and experience sharing. This consequently limits the potential complementarity between new knowledge (technologies) and traditional knowledge.

The Rwandan Vision 2050 and the National Strategy for Transformation (NST1) are major national development programs that inspire agricultural development strategies and policies in Rwanda. These programs are based on Vision 2020 and EDPRS I&II, which phased out in 2013 and 2018 respectively. The National Agriculture Policy and the 4th Strategic Plan for Transformation of Agriculture 2018–2024 (PSTA4) are major guiding policy documents for agricultural development in Rwanda. These are accompanied by sub-sector strategies and policies as well as District Development Plans (MINAGRI, 2018b). The implementation process of the plans and programs follows a vertical flow in a normative way toward the ambitious aspiration to effect a transformation from subsistence to

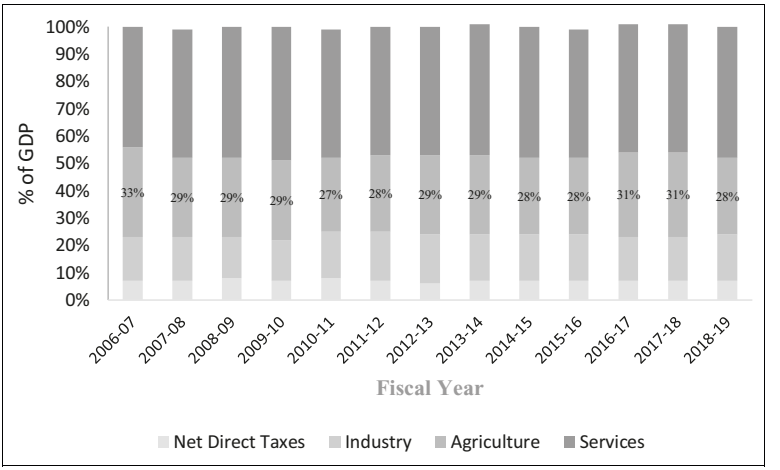

Figure 1. Contribution of the agriculture sector to the national GDP, 2007–2019.
Source: Data from NISR (2019).

market-oriented agriculture which will ultimately contribute to Rwanda's move toward the middle-income countries category by 2025 (Gatete, 2016; MINECOFIN, 2017).

These plans and policies have induced several policy actions aimed at transforming the sector. Various priority areas were set to address major challenges, including agricultural intensification, land and water resources management, agricultural mechanization, agro-processing, agricultural market development with an emphasis on export promotion, the pricing system and certification and standardization for global market integration, among others. Given the importance attributed to increasing production, genetic resource improvement is among the core priorities, with a focus on seed diversification and improvement. This is combined with crop protection efforts, as it is believed that the combination of the two will provide solutions including crops that resist harsh conditions caused by climate change and diseases. In addition, the promotion of agribusiness is seen as a means for extending the agriculture sector's operations, increasing the number of actors involved and connecting agriculture to other economic sectors, including the service sector and other industries. The promotion of agribusiness is effected by supporting the value chains of promising commodities: among those identified as promising are horticulture, dairy, poultry, potato, coffee and tea (MINAGRI, 2018b; MINECOFIN, 2017).

The Rwandan agriculture sector, through its specialized sub-sectors and value chains, accommodates a wide range of stakeholders that contribute to its development in different ways and with different capacities. They are generally grouped into the main categories of farmers, agro-dealers, processors, traders (retailers and wholesalers), research institutes, public organizations (ministries and government agencies) and non-governmental organizations (local and international). All these stakeholders are expected to interact while performing their roles for meeting their collective interest, the development of the agriculture sector. Based on the wide range of stakeholders in the sector and the diversity in operations, it is important to understand how they interact and their role in building the AIS in Rwanda.

Literature review

National innovation system and the THM

A consensus in the literature and among policy circles has more or less emerged about what is meant by innovation, a national innovation system and the Triple Helix and about their relevance for economic growth and national competitiveness and societal well-being. Both the national innovation system model (NIS) and the THM emphasize the importance of interaction among the key actors for knowledge production and sharing, aside from a strong capacity in R&D. The ability to innovate is often related to collective action, coordination, the exchange of knowledge among diverse actors, the incentives and resources available to form partnerships and develop businesses, and the conditions that make it possible for firms and entrepreneurs to use innovation (Chaminade et al., 2018; Etzkowitz and Leydesdorff, 2000; Fagerberg and Srholec, 2008). Technological skills, innovative solutions, functional institutions and stakeholders' capacity (financial and knowledge) are

imperative for the needed systemic approach (Juma, 2015; Lundvall, 2010). Such an approach echoes the importance of joint efforts in policies and policymaking processes as a means for ensuring collective interest in the system and inclusivity. This ultimately defines the functioning and success of the system as policies and aligned instruments play an important role in decision-making for collaborations among actors and investments, leading to high innovation propensity (Mytelka, 2016).

The NIS literature engages directly with the concept of system as a kind of loose metaphor to describe broad relationships among the relevant stakeholders whose activities affect innovation (cf. Lundvall, 2010). In a series of empirical studies, scholars had shown that systems of innovation can be achieved at national or regional level (e.g., while a national system may be more visible in the Netherlands, the regional level prevails in Germany—see Cooke and Leydesdorff, 2006; Isaksen and Asheim, 2002; Leydesdorff and Fritsch, 2006). Moreover, one can analyze whether innovation systems are technology-specific or sector-based (Carlsson, 2006; Malerba, 2007; Pavitt, 1984). The core idea of the regional innovation system (RIS) or the sectoral innovation system (SIS) does not differ from the overall concept of the NIS, except in the level of operationalization (Cooke, 2002; Lundvall, 2005).

The THM is employed to understand the specific roles of three key stakeholders, university, industry and government, and the synergy between them (Etzkowitz and Leydesdorff, 2000). The model encourages closer relations among actors, with each not only playing its own role but also taking over each other's roles, as well as creating hybrid organizations at their interfaces. An example is the science park, in which research results and knowledge developed in a university are transferred to private firms or commercialized in incubators by entrepreneurs with the financial support of governmental agencies. In this model, the traditional university transforms into the "entrepreneurial university" which becomes the main organizational actor. Universities in the THM keep their autonomy but develop reciprocal relations with the other actors (Etzkowitz, 2013; Leydesdorff and Etzkowitz, 1996).[1] Using the THM, analysis can be more specific than using NIS as it embraces interaction among all organizations and institutions at the national level.

Despite some limitations and critique, the THM is being used as a research tool in several studies focusing on both developed countries (e.g., Sweden, Denmark, Netherlands, Finland, Israel) and developing countries (e.g., China, Latin America, South Africa, Kenya). It has become popularized even as a policy framework or concept by numerous national organizations (e.g., Vinnova in Sweden, Magnet in Israel) and supranational organizations (e.g., the European Union) (for more information, see Benner and Sandstrom, 2000; Göktepe, 2003; Jongwanich et al., 2014; Liu and Huang, 2018; Nordfors et al., 2003; Sutz, 2000; Tuunainen, 2002).

Table 1. Policymaking approaches and associated policy drivers.

Policymaking approach	Policy drivers
Policy transfer	Global North practices, global agendas, donors' requirements (practices)
Policy learning	Global North practices, global agendas, donors' requirements (practices), regional plans, sub-regional plans, national plans, sectoral & cross-sectoral plans
Evidence-based policymaking	Research evidence, stakeholders' needs/problems, local conditions

The THM has evolved from a descriptive framework and an analytical tool into a normative model used in many countries and regions to foster technological innovation and economic growth. Many national agencies and ministries in developing countries have tried to learn from the success of developed countries or from countries that have managed to catch up quickly (such as South Korea or China). They have relied on external experts and scholars to obtain the recipe for innovation policy. These experts often simplify the process of knowledge creation and innovation into public–private partnerships in different spatial and other contexts as the key for innovation policy frameworks in many countries (Jongwanich et al., 2014; Leydesdorff and Zawdie, 2010). However, it is still hard for the policymakers or policy analysts to learn from these frameworks and to use the underlying ideas rigorously.

Policymaking approaches and policy goals for innovation

Up to this point, we have discussed the emergence of systemic approaches (NIS, THM) for innovation as a scholarly field. In this section, we delve into a complementary discussion on policymaking approaches and how the choice of policymaking approach can lead to policy actions that influence innovation performance. We give a brief overview of policymaking approaches and how they are related to innovation policy goals. We discuss the literature related to policy transfer, policy learning and evidence-based policymaking. From this discussion, we suggest a simplified analytical tool (Table 1) that we apply to policies and policy instruments to identify key policy drivers and how they orient policy actions that support innovation in the Rwandan agriculture sector.

Policy transfer (whether voluntary or coercive or a combination of both), in particular, between developed and developing countries underlines the partition of countries into "donor/lending and borrowing" countries. It is often labeled as "lesson-drawing" or "lesson-learning," and

countries that look at successful experiences frequently expect that the policy lessons will generate similar success for them (Howlett, 2009; Stone, 2017). This misapprehension, however, ignores the importance of local capacities, competencies, resources, infrastructures and, particularly, local culture and needs. Policy transfer is rarely a perfect process of transmission (Meseguer, 2005).

Policy learning, by contrast, may result in a more coherent adaptation of ideas, policies and practices (Stone, 2017). However, there is no clear-cut distinction between policy transfer and policy learning. Depending on how the transfer is done, there might be a soft transition between the transfer and the learning, but in other cases there may be a direct transfer of policy such as often happens between developing countries (the Global South) and their donor countries (the Global North). Learning occurs in specific institutional contexts: that is, in systemic environments shaped *inter alia* by regulation, law, political culture and the "rules of the game" of economic institutions. These environments of course include policy institutions and actions. Policy learning, like policy transfer (emulation), may therefore fail to capture the holistic nature of problems and solutions. This may result in a lack of support for innovation development, which is the primary motivation for learning from best practices and success stories.

Direct policy transfer, in particular learning and implementing successful policy instruments from one context to another, can be a too complicated and risky option, as there is no detailed blueprint for making innovation happen at a given time in a given place for a given result. The formulation of innovation policies and development plans based on success stories is problematic due to the complexity of the innovation process (Clark, 2016; Stone, 2017). Innovation policy must build on the key characteristics of how innovation comes about: it is uncertain, cumulative and collective (Lazonick and Mazzucato, 2013). It has to take into account national factors, historical path-dependencies, local conditions, economic inequities, demographic challenges and informal economic activity (Fagerberg and Srholec, 2008; Muchie et al., 2003). This requires evidence to inform policy on these issues. Thus, evidence-based policymaking becomes a more efficient and strong approach.

Evidence-based policymaking and stakeholders' engagement are among the effective approaches that are used in places where efficient policies are observed. Policy efficiency at both macro and micro levels solicits a systemic approach with the ability to set priorities and proper resource allocation (Chaminade and Lundvall, 2019; Howlett, 2010; Mytelka and Smith, 2002). Evidence-based policymaking emphasizes that the government must produce policies that are forward-looking and shaped by evidence rather than a response to short-term pressures; that tackle causes not the symptoms. This approach requires a pool of accurate pieces of evidence that will ensure the potential for policy success. Those pieces of evidence are obtained from diverse sources, with research-based evidence preferred in most cases—although the active engagement of actors in the process is also considered a means of capturing real problems in their actual context.

Howlett (2009) considers problem examination as a starting point in policy design for organizing thinking and analytical efforts in a more productive way that can lead to effective and efficient policies and policy instruments. The acquisition of evidence and real problem analysis are key challenging stages in the policymaking process. They are expected to be systematic processes that consider different dimensions in order to generate realistic and implementable policy tools in the context of operationalization. Efficient frameworks and avenues for consultation and experience/ideas sharing play an important role in the process. Based on the complexity of the innovation process, it is hard to rely on a single approach to provide policies and policy instruments that capture all policy demands for conditions to innovate. A balance in the use of these approaches is needed, depending on learning capabilities and the capacity to generate and use evidence. Undeniably, due to the dynamics of globalization, it is often suggested that a mix of policy transfer, policy learning and evidence-based policymaking is "on the rise" as an empirical phenomenon (Davis, 2009; Howlett, 2010).

However, navigating all the dynamics involved in this mix is challenging, and criticisms have been emerging with regard to evidence-based policymaking, which is considered an efficient policymaking approach in many places. Criticisms concern how the evidence is generated, its accuracy and objectivity, and how it provides answers to policy problems. There are arguments about the influence of personal and policy agendas in evidence production as well as uncertainty in the research process, which is considered the main source of trustworthy evidence. There is also concern that policymakers can manipulate evidence to make sense of their own narrative or political agenda (Greenhalgh et al., 2020; Hulst and Yanow, 2016). Thus, it may be wise to adopt any policymaking approach with caution and to engage in critical reflections that will allow a balanced view of the policy problems and the policy options to answer those problems.

In this paper, we build on the fundamental principles of the above policymaking approaches to understand how Rwandan agriculture policies and policy instruments are designed and how they provide an operational framework for innovation. As noted above, lessons are drawn from success stories in developed countries (Global North practices) and international development goals and programs (the global agenda) or are imposed by donors (donors' requirements). Moreover, some lessons are learned within regions (from regional plans) or within a country at different levels (national, sub-regional, sectoral plans). As for evidence, it can be acquired through research, the analysis of stakeholders' problems and the analysis of local conditions (Howlett, 2010; Stone, 2017). These sources of lessons and evidence are in principle the main

policy drivers that provide the foundation of policy orientations. However, the influence of power and politics cannot be neglected in the policymaking process. On this basis, we designed a guide (Table 1) to organize policymaking approaches and their associated policy drivers.[2] The guide helps in the exploration of how policies and policy instruments in the Rwandan agriculture sector support innovation activities for facilitating the emerging AIS. It helps to connect the policymaking approach, policy drivers and policy initiatives, and how stakeholders build on them to orient innovation activities that increase the innovation propensity in the sector.

Methodology

In this study we use both primary and secondary data collected through semi-structured interviews and a structured review of official documents to address our research question. As a point of departure for the empirical study, we have utilized secondary data gathered from different official documents and policy reports for the agriculture sector at different levels (national, regional and international).[3]

In addition to the secondary data, we collected primary data using semi-structured interviews with key stakeholders, including policymakers, researchers, farmers, industrialists (processing) and non-governmental organizations (NGOs) participating in the Rwandan agriculture sector. There were two rounds of interviews: the first round was conducted in December 2017–February 2018 and the second was conducted in January–February 2019. Interviewees were selected purposively in a systematic way based on their institution, position, seniority and experience. In government institutions, we selected senior policymakers; in research and academic institutions, senior researchers; and in farmers' cooperatives, cooperative managers. For NGOs and the private sector, staff in decision-making positions were selected. A specific guide was developed for each round of interviews, with approximately 10 questions (see Appendix 1).

In the first round, we interviewed 16 policymakers, 6 researchers and 2 representatives from NGOs. We focused on more general issues related to the promotion of innovation, the institutional setting and the collaboration and policy environment. The second round focused specifically on the Rwandan agriculture system and four policymakers, three researchers from agricultural universities, eight farmers and five representatives from industry (private firms in agro-processing) were interviewed. The main themes for the interviews were the policy framework for promoting innovation, policymaking approaches, stakeholders' interaction and their role in the agriculture innovation system, and major challenges for innovation in agriculture.

Interviews lasted for between 30 minutes and 1 hour for both rounds and for all stakeholders. They were conducted as a guided discussion, with notes taken during the discussion and edited for analysis. The interview guide included an introductory section setting out the purpose of the study and with a request for consent. Before each interview, interviewees granted their consent. Their identity was kept anonymous and interview notes were treated as confidential, with only researchers in the team having access to them.

The interview notes were analyzed using thematic analysis, based on the key parameters relating to our research question—these included the policymaking approach (Table 1), major policy initiatives from policy instruments, the role of stakeholders in the innovation process and institutional set-up. The NIS and TH models were used as frames of reference for analysis of the themes. These concepts were instrumental in analyzing the stakeholders' categories, their functions and their modes of interaction.

Findings

The empirical findings from the secondary and primary data are organized into three main themes to address our research question: (a) stakeholders and their roles in fostering innovation in the Rwanda agriculture sector; (b) the institutional set-up to facilitate the innovation process; (c) major policy instruments and policymaking approaches to promote innovation in the Rwandan agriculture sector.

Stakeholders and their roles in innovation

Stakeholders in the Rwandan agriculture sector are grouped into farmers, government, non-governmental organizations, the private sector and knowledge institutions. The farmers' group is mainly composed of farmers' federation and cooperatives as well as individual farmers, small-scale farmers and large-scale farmers. The small-scale category consists of farmers with less than 0.7 ha of farming land, while large-scale farmers have 1 ha or more (Ayalew Ali and Deininger, 2014; Rwirahira, 2009). The NGO category comprises both local and international bodies (including UN agencies and regional/transboundary organizations directly or indirectly engaged in the agriculture sector). Line ministries, aligned agencies and local administration entities are the main components of the government category. The private sector category is composed of agro-dealers and agribusiness entrepreneurs, including industries. Research and training institutions (i.e. higher education) make up the knowledge institutions group.

These stakeholder groups have a wide range of roles and functions to perform for the development of innovation in Rwanda's agriculture sector. The government plays the central role of providing an operational environment through planning and policymaking. Knowledge institutions conduct research and technology transfer to provide needed skills and technology to address problems in the sector. The research dissemination and technology transfer roles are accomplished through interaction—still meager due to weak collaborations and a lack of joint activities.

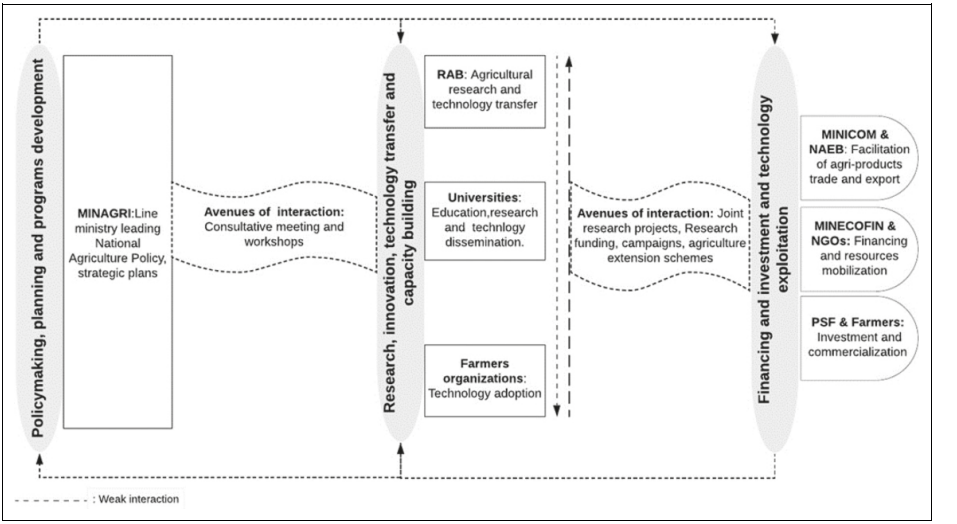

Figure 2. Status of stakeholder interactions in the Rwandan AIS.
Source: Authors' elaboration.
Note: MINAGRI: Ministry of Agriculture and Animal Resources; RAB: Rwanda Agriculture and Animal Resources Development Board; NAEB: National Agriculture Export Board; MINICOM: Ministry of Trade and Industry; MINECOFIN: Ministry of Finance and Economic Planning; NGOs: Non-Governmental Organizations; PSF: Private Sector Federation.

The interaction involves knowledge institutions as technology providers, public agencies and NGOs as facilitators and farmers as technology end-users. Innovation propensity is expected to increase through interaction and mutual learning among the stakeholders, particularly between knowledge institutions and technology end-users (farmers and industries). To translate all these efforts into economic significance, roles related to financing and commercialization are fulfilled by the private sector.

As noted above, interaction among stakeholders is still low and this was highlighted by all the interviewees (Figure 2). However, they recognized emerging efforts to enhance interaction through consultative meetings and workshops, although these means are not seen as satisfactory in light of the high expectations of research, technology and innovation as the main drivers for the transformation of the agriculture sector. A cooperative representative commented:

> We are not consulted for technologies that are brought to us and sometimes we find them not useful based on our needs. And the same happens for different training that we attend; they are many times like normal classes and yet we want hands-on practices to increase yield in our farms.

This low level of satisfaction is attributable simply to the lack of effective and efficient mechanisms for interaction. Tools and frameworks such as innovation platforms, Farmers Field Schools (FFS), the annual national agriculture show and professional platforms and ICT for Agriculture (e.g., the ESOKO platform initiated in 2008) were initiated as efforts to overcome collaboration challenges for research, innovation and technology transfer. However, it is still difficult to sustain the use of these tools and to realize a positive impact, as highlighted by a researcher at the Rwanda Agriculture and Animal Resources Development Board (RAB):

> We have been trying different extension tools but it is hard to realize the impact as many of them require ownership of farmers and investment from different actors. An example is the initiation of Innovation Platforms: at the beginning, with donors' funds, they were performing well but after the project most of them failed because farmers could not sustain them. The same for FFS, after we have completed the trials, it is hard to observe farmers using technologies in their own fields.

Nevertheless, the government has made efforts to encourage joint activities and planning among stakeholders (mainly government, the private sector and universities) at different levels. An example is the Joint Development Action Forum (JADF) established in 2007 to facilitate joint planning among development actors through active participation, dialogue and the coordination of stakeholders'

Table 2. Policy instruments and policymaking approaches to support innovation.

Main policy/policy instrument	Main approach	Major policy drivers	Key policy initiative/orientation
National development vision & strategies: Vision 2020 (2002, revised 2012), Vision 2050 (2020) and NST1 (2017)	Policy transfer and policy learning	Global agendas, donors' requirements, and Global North practices	Promotion of knowledge-based economy, predefined development priorities, vision for Rwandan agriculture
National policies: National Agriculture Policy (2018) and National Industrial Policy (2011)	Policy transfer and policy learning	Regional plans, sub-regional plans, national plans and sectoral & cross-sectoral plans	Promotion of agri-technologies, establishment of research programs
Sector strategies: Strategic Plan for Agriculture Transformation IV (2018)	Policy transfer, policy learning and evidence-based policymaking	National priorities and needs and local conditions	Promotion of agriculture technologies, specialized research and technology transfer programs, market diversification
Local strategies: Crop Intensification Program and Land Use Consolidation Act (2008)	Policy transfer, policy learning and evidence-based policymaking	Donors' requirements, national priorities and local conditions	Promotion of agri-technologies (improved seeds, processing, etc.), community-based technology transfer tools

Note: This table is based on authors' analysis of policy documents (MINAGRI, 2018a, 2018b; MINECOFIN, 2012, 2017, 2020; MINICOM, 2011; USAID, 2014) and interviews with policymakers.

interventions in decentralized entities, like districts. In addition, farmers' federations are being sustained and are part of JADF. However, it will take time to achieve positive outcomes from such initiatives. As one of the senior policymakers interviewed commented, "It will take time to see strong collaboration and harmonization of plans among actors to boost innovation in agriculture."

The level and quality of interactions among stakeholders, investment and the consideration of critical issues in a specific context are key for increasing innovation propensity (cf. Lundvall, 2007b). These are likely to be observed if there are: a joint planning framework that allows what is in the collective interest to happen; participatory research approaches; active learning processes; and a clear perspective on the complexity of the system by considering all dimensions (Ngaboyisonga et al., 2014). Well-accomplished stakeholder roles are essential to these factors, and the adoption of engaging avenues for interaction can help to overcome the lack of cooperation in emerging innovation systems such as the Rwandan AIS (Dosso et al., 2018; Jiggins et al., 2016).

Institutional set-ups to facilitate the innovation process

The above discussion provides an overview of the actors involved in building the Rwandan AIS. However, as pointed out by Lundvall (2010), to stabilize and mature innovation systems need strong institutions to support actors (organizations) in performing their roles and functions in the innovation process. In our study, we noted that institutional frameworks were being set up to ensure proper coordination and collaboration. Specialized institutional structures, policies, law and regulatory frameworks are major institutional patterns that are emerging. Specialized public agencies and their regulatory frameworks have been established to facilitate research, technology transfer, innovation, capacity building and agribusiness (including export). Among the established agencies are the Rwanda Agriculture and Animal Resources Development Board, which deals mainly with research and extension activities in the agriculture sector. The National Agriculture Export Board was established to promote agribusiness, particularly export. In addition to these specialized agencies in agriculture, the National Industrial Research Development Agency was put in place to promote industrial activities in different sectors of the economy, including agriculture. All these institutional structures are aligned with different policies and policy instruments to support innovation activities in the agriculture sector. The National Agriculture Policy, the National Industrial Policy and the Strategic Plan for Agriculture Transformation are among the key policies that have been put in place (Table 2).

Moreover, farmers' organizations (cooperatives and federation) have been established to facilitate technology transfer among farming communities. Capacity building schemes have also been developed, from formal education to farmers' training. There are specialized agriculture universities, colleges and technical colleges. For example, 6 of 22 certificate courses offered as Technical Vocation Education and Training are in agriculture (WDA, 2018) and there are Higher Learning Institutions which specialize in agriculture (HEC, 2019).

In addition to institutional structures, there are regulations and regulatory frameworks that favor the adoption of new technologies and facilitate dynamics in markets from the local to international level. The interviewed stakeholders from the private sector appreciated the established

subsidy schemes for the importation of technical equipment as an important regulatory mechanism for supporting product diversification and enhancing their innovation propensity. The same applies to the local certification and standardization framework which helps local industries to ensure the quality of products, particularly for agro-processing and export.

Although there was an appreciation of these efforts, the stakeholders also highlighted issues that were hampering the current institutional structure in facilitating innovation in the agriculture sector. These included a lack of budget to support innovation activities, limited interaction among organizations, a lack of consistent strategies to build internal capacities and a lack of policy feedback channels. Institutional coordination, trust among actors and institutional stability were other areas considered in need of improvement. As highlighted by a researcher at an international NGO, there is a need to match institutional strategies and policies with resources allocation:

> Both the National Agriculture policy and the 4th strategic plan for the transformation of agriculture place a lot of emphasis on research and innovation (actually it's the first pillar in PSTA4). In other words, government policies are supportive. The main challenge is that a very limited budget is made available for research and extension.

Strong and operational facilitating frameworks in terms of organizational setting, policy tools and the legal environment are essential for the institutional capacity development that can serve as a point of departure for the promotion of innovation. Institutional stability and coordination determine the performance of the innovation system as well as the type of innovation that can succeed in it (Gregersen and Johnson, 2005). Local conditions are also important, since the successful impact of public policies, regulations and law on innovation development depends on mutual understanding and shared responsibility coupled with equity and openness among stakeholders, as suggested by Mytelka (2016) for the case of innovation systems in transition. Thus, the current institutional set-ups to support innovation in the Rwandan agriculture sector have shortcomings that need to be systematically addressed in building a stable and functioning AIS.

Policymaking approaches and policy instruments to promote innovation

Rwanda has put in place policies and policy instruments (Table 2) to support innovation for agriculture sector development and national socio-economic development in general. They provide key priorities and implementation guidance to increase innovation propensity in the agriculture system, and have been formulated using different policymaking approaches. Policy transfer and policy learning appear to be the most popular approaches in the Rwandan agriculture policy cycle, whereas evidence-based policymaking is less in evidence. Policy transfer is observed mainly in development plans influenced by global and continental agendas. Policy learning and evidence-based policymaking are observed in contextual priority-setting based on national realities or specific agro-ecological zones. Consultation with stakeholders is used as the main tool in the learning process and the acquisition of evidence.

For policy transfer and learning, global and regional development agendas are the main policy drivers. The Sustainable Development Goals of the United Nations, Agenda 2063, the Comprehensive African Agriculture Development Plan (CAADP) and the East African Vision 2050 are the main frames of reference and influence national priorities (African Union Commission, 2014, 2015; EAC, 2015; NEPAD, 2003; United Nations, 2015). These agendas are seen as motivations to set national development strategies targeted at global integration and harmonization with regional initiatives. Rwanda's Vision 2020 and Vision 2050 are the main development strategies that provide orientation to other national policies and strategies. From these guiding strategies, there is a vertical transfer of development priorities from central government to specific sectors, including agriculture. The transfer of ideas and priorities appears to be state-driven, as highlighted by one of the policymakers interviewed: "We follow the guidelines from the national leadership." However, consultations with stakeholders at workshops and meetings provide the main sources of evidence and interaction that inform policies. These consultations, though, are perceived by some stakeholders (particularly farmers, researchers and processors) as unsatisfactory because they follow a predefined agenda and the audience may not be well informed about the policy problems that need to be addressed.

Given the process described above, the level of learning is still low because policy is formulated top-down, with the government leading. Farmers in particular claim that policies do not take into account their problems, reflecting the dominance of policy transfer in policy learning and evidence-based policymaking, as lessons learned are not put into context so that policies do not capture the practical reality faced by stakeholders. To enhance learning and the contextualization of lessons learned from the global and regional agendas, there is a need to enhance the active engagement of stakeholders and consider bottom-up interactions with research-based evidence.

However, although the policymaking process has shortcomings, the policies and policy instruments that are in place do provide an orientation toward what needs to be done to establish favorable conditions for innovation in the Rwandan agriculture sector. Major policy goals and actions emphasize enhancing research and technology transfer efforts as a means of addressing the issues identified. An example is Pillar 2 of the National Agriculture Policy

(2018), which sets out a direction for the agriculture research agenda and policy actions for "technological upgrading and skills development" in the Rwandan agriculture sector, and identifies priority areas for research and technology transfer efforts. Accordingly, research programs and infrastructures have been developed to address seed improvement, disease and pest control, and genetic resources improvement in both animals and crops as major challenges in the sector.

Infrastructures like gene banks, seed centers and germplasm centers have been established to facilitate research and agricultural technology advancement. As means for community outreach and technology dissemination, technical tools for helping farmers have been developed and platforms for interaction and capacity building have been initiated. The Farmer's Field School (FFS) is among the policy instruments initiated to facilitate technology transfer between researchers and farmers (Gahakwa et al., 2014). Policies indicate an interest in innovation platforms, FFS Master Trainers and Farmer Promoters as facilitators of technology transfer and innovation development (MINAGRI, 2018a). However, these are still at the early stage of adoption and face challenges of coordination, ownership and investment (Adam et al., 2018).

Discussion

The development of an AIS requires identification of stakeholders, understanding of their behaviors, practices and habits, and analysis of triggers of innovation such as the policy framework, actors' interactions and dynamic capabilities (cf. Jacob, 2016; Juma, 2015; Klerkx et al., 2012; Schut et al., 2015). In this study, we noted that the main stakeholders were in place and the main functions could be accomplished in the Rwandan AIS. However, there is still only limited interaction among stakeholders, and interaction is important for the performance of any innovation system. The underlying causes for the limited interaction relate to the lack of an appropriate framework and to behaviors and habits. A lack of trust and collective interest among stakeholders, a common problem in emerging innovation systems, is apparent in the Rwandan AIS. To overcome this, previous studies (see Chaminade et al., 2018; Etzkowitz and Leydesdorff, 2000; Lundvall, 2007a) suggest early interaction in knowledge production and transfer processes, particularly between industry and the higher education system. Clark (2002) and Mytelka (2016) emphasize the importance of proper governance and appropriate policy interventions to support innovation.

The potential of policies and policy instruments to support innovation depends on how responsive they are to pertinent and complex problems in the system. This in turn depends on the policymaking approach and how policy goals are identified (Howlett, 2010; Mytelka and Smith, 2002). The use of appropriate frames of reference and policy drivers is a key factor in successful policy formulation (Dobbin et al., 2007; Hulst and Yanow, 2016). This study identifies policy transfer and policy learning as the main approaches used for many policies and policy instruments designed to support agricultural development in Rwanda. The adoption of evidence-based policymaking is still low, with only national needs identified through consultation with stakeholders used as evidence. The use of research evidence is very low and this weakens policy instruments, which are alleged to be under-informed and insufficiently responsive to local conditions. In policy transfer and policy learning, global and regional agendas, donors' requirements and best practices in the Global North are the main policy drivers. Combining realities of the local context with these drivers requires hands-on experience in evidence-based policymaking and access to reliable and accurate evidence that clearly articulates issues that policy needs to address.

However, policy learning and policy transfer may in principle be obstacles to the promotion of innovation in Rwanda's agriculture sector. The adopted approaches and practices in the transfer and learning processes are key: they may lead to unexpected results if they are not carried out with due consideration and caution. Direct policy transfer can be inappropriate in many contexts, whereas policy learning may offer a good option the lessons learned can be adapted to the local context. The policy learning process, however, requires sufficient capacity to reflect on the core issues and on how the lessons can be usefully applied and contextualized. This involves human capital, infrastructure and efficient institutional structures (Borrás, 2011; Mytelka and Smith, 2002; Sanderson, 2002).

The ensure the appropriate application of lessons learned and best practices to increase innovation propensity in Rwandan agriculture, we recommend analysis of how stakeholders interact in specific activities (production, processing and commercialization), as particular issues may require different approaches depending on how the relevant activities are performed. This approach will contribute to an understanding of the merits of an AIS and the most appropriate policy actions and tools. The enhancement of interaction, particularly among higher education, government and industry (or farmers) will produce more knowledge-based solutions and increase the technology/innovation absorption capacity.

The policies and policy instruments discussed in this paper tend to consider innovation as a linear process from inputs to outputs—they do not seem to consider innovation as a socially embedded interactive learning process. This perspective may conflict with the intended move toward inclusive development and a knowledge-based economy, slowing down innovation uptake despite high expectations (Chaminade et al., 2018; Mytelka, 2016). A more systematic and inclusive approach in policymaking that uses research evidence and farmers' most critical needs would

be more helpful, as suggested by Juma (2015) as a strategic action for African agricultural development. Such an approach would contribute to the development of a dynamic AIS built on proven knowledge and real societal problems.

It is important to understand that farmers (or society at large, as the main beneficiary of innovation) do not want models per se; rather, they are in need of information, tools and infrastructure that will enhance their productivity and help them solve problems. Policy tools must therefore be embedded in decision support mechanisms that respond to farmers' and society's needs. Although it is challenging to change the policymaking process, this study highlights the importance of making that process more inclusive: it should be open to feedback from all stakeholders with a bottom-up approach. In this way policy goals and policy tools can be aligned with the end-users' (farmers') problems and expectations. Another important area for improvement is resource mobilization and resource allocation. The current system needs a more consultative approach among stakeholders for the efficient use of resources; joint initiatives that allow synergetic actions and complementarities among actors can serve as a point of departure for this policy orientation. Although these suggestions cannot be implemented overnight, they may serve as a starting point for future studies that focus on the improvement of innovation policy in general.

Conclusion

In this paper we have explored the question of how policies and stakeholder interactions contribute to the emergence of the Rwandan AIS. We thus contribute to the ongoing debate about factors and conditions for emerging innovation systems in developing countries, particularly African countries. Despite some limitations, this study is one of the first to focus on the AIS in Rwanda. Several scholars (Juma, 2015; Lundvall, 2007a; Muchie et al., 2003; Scerri, 2016) have contributed to this debate and have argued that the factors and conditions needed for innovation systems to evolve are context-specific and depend on the operational environment, economic structures, historical conditions and the collaboration of stakeholders. The definition of an innovation system emphasizes the importance of policies as a factor in influencing the innovation process (see Metcalfe, 1995). Mytelka and Smith (2002) and Hall et al. (2005) also stress the importance of the policymaking process and of how contextual issues are taken into account to meet policy goals.

In keeping with these studies, this paper highlights the potential significance of an AIS for Rwanda while setting out the obstacles to innovation policymaking in the agriculture sector. It is clear that stakeholder interactions are a key factor in building the AIS, but it is hard to create synergies in an environment with limited interaction and a lack of strong facilitating frameworks. Stakeholders' capacity to perform their roles and functions is also an important factor in creating synergies. We find that policymaking approaches are key in developing appropriate conditions for innovation performance. The study shows that policy transfer and policy learning may not favor innovation development because they reflect an understanding of innovation as a linear process. However, their combination with evidence-based policymaking should lead to policy actions that promote innovation.

Moreover, it is important to increase awareness among all stakeholders that a well-functioning innovation system cannot be established instantly. A systemic approach that encourages public–private partnership—for example, the intensification of university–industry relations in accordance with the THM—is a strategic point of departure in the initial phase. This can sharpen the focus on the key preconditions for capacity building and public–private partnership and avoid the riskier route of attempting to develop a broader innovation system with a wide range of stakeholders and complex interaction while lacking the basic conditions for collaboration.

Our empirical findings show that it is important to frame policies and policy instruments around stakeholders' problems and to take into account r the available capacity to materialize them in the Rwandan context. This does not mean that Rwandan policies and plans should not consider global issues, but rather that strategic and systematic approaches to positioning Rwanda in terms of global trends should be adopted. Policy learning for the promotion of innovation in the agriculture sector in Rwanda can lead to positive outcomes if it is applied through active learning and efficient policymaking mechanisms. The main point of this paper has been to stress the essential complementarity between stakeholder interaction and policy dynamics, at least in the context of agriculture in Rwanda. While there is no question that R&D is an essential component of an effective innovation system, it is also clear that R&D activities need to be supplemented by other mechanisms designed to ensure productivity improvements, especially for the poor farmer.

Future research and policy discourse need to take into account the difficulties of policy learning and policy transfer in the contexts of developing countries. The shortage of good examples of the use of research for innovation uptake in agriculture in Rwanda, or in other developing countries, is not reducible to discernible factors such as lack of finance or lack of research skills, since much more could be made of existing capacities. What is really needed are institutional structures that encourage interaction between the key stakeholders of innovation—universities, industry and government. Only when that is successfully achieved will the innovation propensity increase and the AIS become, ultimately, efficient and sustainable.

On a final note, agriculture is not an isolated sector; it is closely connected to several others. Thus innovation in the agriculture sector does not happen in a vacuum but in close connection with sectors such as industry, service, ICT, energy, finance and health. We therefore suggest that our single-sector focus be expanded to a cross-sectoral study to examine innovation policymaking in other sectors as well as to deepen understanding of national innovation systems. Rwanda is participating in international and regional initiatives and collaborative projects (e.g., within the East African Community), and our study provides insights into such partnerships by presenting the situation in Rwanda. Cross-national and cross-regional studies, however, will further our current understanding of innovation policymaking and agriculture innovation systems in developing countries like Rwanda.

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Notes

1. A related concept to the NIS and TH models is "Mode 2-knowledge production." The "Mode 2" concept takes into consideration only one aspect of the innovation system (knowledge production), while the Triple Helix perspective on innovation systems is wider. "Mode 2" claims that in the knowledge-based economy there is a shift toward interdisciplinary science, which takes place in the context of application. Moreover, the "Mode 2" thesis claims that boundaries between the university and the surrounding environment are almost totally blurred (Gibbons et al., 1994).
2. "Policy drivers are defined as broad aims, targets or statements that are considered to be desirable by the various bodies of government or non-government organizations in satisfying their overall goals such as 'maximising social welfare' and 'staying in power'. The types of policy drivers vary by organisation and may be complementary or contradictory. They may also change over time as new doctrine is implemented or new research findings put into practice" (Shires, 2003).
3. The main secondary data sources were: EICV 5: Integrated Household Living Conditions Survey (2018), SAS: Seasonal Agriculture Survey, 2017–2019 and the GDP National Account Database (2019).

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Appendix 1

Interview guides used in primary data collection

Table 1A. Interview guide for Round 1: Key actors (policymakers, researchers and private sector).

Initiating questions/points of discussion
1. Are you familiar with the national innovation system (NIS) concept in your institution? If yes, what are your views on it?
2. What do you consider as innovation and what forms of innovation is your institution interested in?
3. What is your view on how innovations emerge and are disseminated?
4. What are your views on the role of innovation in achieving the national economic development goals?
5. How do you view the policy and legal frameworks in promoting innovation for development?
6. In what socio-economic sectors can innovation contribute the most to economic transformation or development goals?
7. With whom does your institution work for research and innovation matters?
8. How are research and innovation managed in your institution?
9. How does your institution promote the move from research to innovation?
10. What are the funding mechanisms for R&D in your institution?
11. What are the mechanisms for funding innovation activities in your institution?
12. How does your institution facilitate (get involved in or support or promote) the move from innovation to entrepreneurship?
13. What factors do you think are hindering or slowing the move from innovation to entrepreneurship?
14. What are the mechanisms for capacity and competence development for innovation available in your institution?
15. What is one strategy that you think could boost research and innovation uptake in Rwanda?
16. Concluding statement: Is there anything you wish to be done in the future to improve the performance of your institution in R&I promotion and Rwandan NIS development in general?

Table 1B. Interview guide for Round 2: Policymakers in the agriculture sector.

Initiating questions
1. What types of innovation do you think are promising in the Rwandan agriculture sector?
2. What do you think are the factors leading to these types of innovation or decisions to innovate?
3. How do you find government policies and strategies enabling for innovation development?
4. Who do you think are the key actors to boost innovation in the Rwandan agriculture sector?
5. What do you recognize as major forms of interaction (collaboration frameworks) for these actors?
6. What is the form of knowledge that you consider most important in contributing to innovation development in the Rwandan agriculture sector?
7. Concluding statement: Is there anything you wish to be done in the future to improve innovation propensity for the actors in the Rwandan agriculture sector?

Table 1C. Interview guide for farmers and processors.

Initiating questions/points of discussion
1. What types of innovation do you think are promising in the Rwandan agriculture sector?
2. What do you think are the factors leading to these types of innovation or decisions to innovate?
3. How do you find government policies and strategies enabling for innovation development?
4. What is the form of knowledge that you consider most important in contributing to innovation development in the Rwandan agriculture sector?
Specific for the value chain
1. How do you generally describe the potato/tea value chain in Rwanda?
2. How do you perceive current industrial development in the value chain (potato/tea)?
3. What are the major products (tea/potatoes) and their targeted market?
4. What are the driving factors for your product specialization/new product development?
5. How do you select your technologies to be used in the innovation process?
6. Where do you acquire your technologies and other needed skills to innovate?
7. What are your considerations in technology selection?
8. What are your considerations in technology adoption?
9. How ready is your personnel to adopt new technologies?
10. How do you access the new technologies?
11. Who pays (covers the cost) of the new needed technologies?
12. Concluding statement: Is there anything you wish to be done in the future to improve innovation propensity for the actors in the Rwandan agriculture sector?

Paper IV

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Technology and innovation trajectories in the Rwandan Agriculture sector: Are value chains an option?

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Technology and innovation are important in addressing complex problems in the agricultural sector in many developing communities. However, ways and mechanisms to integrate them in the agricultural sector are still a challenge due to the lack of clear pathways and trajectories. Value chains are seen as a strong policy instrument to increase profitability in the agricultural sector; there is also debate around whether value chains can be a potential option to organize technology and innovation trajectories in agriculture. This paper contributes to this debate by exploring the question of how value chain interactions are organized for producing, transferring and using knowledge in the Rwandan agricultural sector. Interviews with relevant value chain actors and a review of reports and scientific literature were used to explore this question. Empirical findings show that value chain structural organization can be an entry point to mainstream technology and innovation. However, this requires building synergies and complementarities among actors. Interactive learning among value chain actors is imperative, with the use of both scientific and indigenous knowledge. Linking value chains to innovation systems is one option to explore for maximizing the potential of value chains in integrating technology and innovation in the agricultural sector.

Keywords: agriculture, innovation, technology transfer, innovation system, value chain

Introduction

Technology and innovation are in many cases considered as important drivers for the agricultural sector development. The promotion of technology and innovation for the agricultural sector is motivated by the need for increasing yield, reduce post-harvest losses and increase the quality of produces (Juma 2015; Schut et al. 2015). This is expected to be achieved by applying technologies and skills for improving practices, inputs as well as market systems. The supply of and demand for agricultural technologies and innovation involve multidimensional interactions among actors. This emphasizes interdependence, networking, social interactions and complementarities among actors (Klerkx and Leeuwis 2008; Madzudzo 2011). All actors (mainly researchers, government and private sector) play significant roles in producing, transferring and using technologies and innovations that are responsive to complex problems in the agriculture sector (Hall, Mytelka, and Oyeyinka 2005; Juma 2015).

The process of producing, availing, accessing and using technologies and innovations is important but it is also challenging. It requires stakeholders' interaction at different stages, particularly for stages of problem identification, solutions finding and adoption of provided technological solutions. This involves complex interactions and proper allocation and use of resources. Approaching these complex interactions and the efficient use of resources requires holistic and systemic mechanisms. All these aim to ensure that provided solutions fit into the context and can sustainably provide positive outcomes. The dissemination and absorption of technological solutions require efficient organization and pathways to channel them through different activities (Chung 2002; Hall, Mytelka, and Oyeyinka 2005; Malerba 2005). However, interactions among these actors require systemic approaches. It is important to create or identify potential avenues for such systemic approaches (Hall, Mytelka, and Oyeyinka 2005).

Innovation Systems (IS) and the Triple Helix Model (THM) are commonly used frameworks to understand how such systemic mechanisms can be organized to meet the intended developmental outcomes, economic growth (Lawton Smith and Leydesdorff 2014; Lundvall 2005). An innovation system is constituted by different elements, which interact in the production, diffusion and use of new and economically useful knowledge. The main elements are organizations and institutions. In the context of IS, organizations are universities, research organizations, government, firms and enterprises. Whereas institutions are the associated economic structures, regulations, rules, law, policies, norms, routines and behaviour among organizations. Interactions and learning within and among organizations are the main processes in IS (Chaminade, Lundvall, and Haneef 2018; Lundvall 2010; Metcalfe and Ramlogan 2008).

To streamline the understanding of these processes, the THM complements the IS. It is used to analyze the relationship between universities, private sector (industries) and government. The THM is a model of the structure to organize empirical analysis of dynamics underlying interactions among and within organizations of the Innovation System. This can be achieved by exploring the key functions of wealth generation, organized knowledge production and organization control that capture cultural and behaviour patterns of actors

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engaged in the interactions involving the production and use of knowledge, which form part of IS (Etzkowitz and Dzisah 2008; Leydesdorff and Etzkowitz 1996; Leydesdorff and Zawdie 2010).

IS exist at different levels, like national, regional and sectoral. The Agricultural Innovation System (AIS) is one of sectoral innovation systems (Baskaran and Muchie 2017; Hall, Mytelka, and Oyeyinka 2005; Lundvall 1998; Malerba 2005). The AIS is considered as a framework to analyze complex problems in the agricultural sector and find ways to provide innovative solutions that improve productivity (Schut et al. 2015). Agriculture commodities' value chains are potential entry points to diagnose these problems. Localization of problems in specific value chains is important in the process of producing needed knowledge and skills to provide innovative solutions (Janssen and Swinnen 2019). However, it requires a more systemic approach due to the nature of problems in the agriculture sector, which are multi-dimensional (soil fertility, crop varieties, pests and crop diseases, post-harvest, market, access to finance and value addition). The multi-dimensional characteristic of agricultural problems involves multi-stakeholder dynamics and interactions at different levels (Farm, cooperative, sector, national, etc.) (Blay-palmer 2005; Madzudzo 2011; Weyori et al. 2018).

The concept of value chain captures a sequence of related and interdependent activities that are undertaken to avail a product or a service through different stages of production and delivery to final consumers, and finally to disposal or recycling. Commodity value chains play important role in organizing interventions that aim at improving profitability in different sectors of the economy, including agriculture (Crescenzi, Pietrobelli, and Rabellotti 2014; Gereffi 1999). They facilitate channelling policy initiatives, diffusion of new technologies, channelling information and allocation of resources (Faborode and Ajayi 2015; Janssen and Swinnen 2019). However, all these are dependent on interactions among value chain actors and their capacity to make a profit out of the available resources (technology, innovation and infrastructure). The organization of value chain activities has implications for relationship building, resource allocation, technology transfer and adoption as well as access to skills and competence development (Gereffi et al. 2001).

A commodity-based value chain is one of the proper ways for organizing and tracing innovation development in the agricultural sector as each value chain may have its special considerations and diversity in ways that activities are performed (Gibbon 2003). It is thus important to understand how value chain structural organization contributes to building production and innovation capacities, particularly in developing countries with emerging innovation systems (Jurowetzki, Lema, and Lundvall 2018). Porter (1985) suggested a basic standard approach to analyze value chains in order to be able to understand key value chain activities at different stages and how value chain actors are involved to undertake these activities. Porter's value chain analysis approach categorizes value chain activities into two main categories, primary activities and support activities. The primary activities include inbound logistics (mainly production activities) and outbound logistics (e.g. processing, packaging and delivery). These primary activities require support activities, where technology and innovation play an important role. Undertaking value chain activities involve interactions among actors through which actors acquire and share skills and competence (Gereffi 1999; Lema, Rabellotti, and Sampath 2018). In this paper, it is contended that the understanding of specific commodity value chain structures and interactions can provide insights on how interactive learning processes can be facilitated for achieving efficient use of technology and innovation to develop the agricultural sector.

From the above point of view, understanding interactions within and among value chains can serve as a basis to understand technology and innovation trajectories within innovation systems. In emerging innovation systems, this can be explored as a co-evolution of value chains and innovation systems. According to Lema, Rabellotti, and Sampath (2018), in principle, this co-evolution builds on the potentials of the two concepts, such as systemic thinking and actions as well as organizational structures and governance. Organizational structures and governance in value chains are potential for developing systemic actions. However, all these require smooth relationships and supporting tools for interactions, which can be explored and experimented through the Triple Helix Model (Leydesdorff and Zawdie 2010). All these are dependent to different conditions and dynamics that in most cases are context-specific. In the context of developing countries, it is important to understand how these concepts can be exploited with their different potentials to facilitate the use of technology and innovation in different economic sectors and for overall socio-economic development.

In the context of Rwanda, the agricultural sector plays an important role in socio-economic development through income generation, provision of food and employment. It contributes around 28% of the national GDP and around 70% of the total population in Rwanda are employed in the agriculture sector, of which 80.2% live in rural areas (NISR 2018, 2019a). Its development vision focuses on a shift from subsistence agriculture to modern market-oriented agriculture. Traditionally, the market was based on exchanging goods among farmers based on the supplies and demands in the communities (Ayalew Ali and Deininger 2014; Bizoza and de Graaff 2012). In this shift, commodities value chains' specialization and land use consolidation are among the major national strategies to transform the agricultural sector in Rwanda. These strategies are used for both subsistence and cash crops (industrial crops) (MINAGRI 2018b; NISR 2019b).

In Rwanda, commodities value chains are associated with regional crop specialization that is mainly based on agro-ecological zones and crops' adaptation. Irish potato, maize, banana and cassava are the main staple crops produced in different parts of the country, with the North-West region as the big producer of potato in the country (around 76% of the national production). Tea and coffee are the main cash crops and contribute

considerably to the Rwandan agriculture export. Coffee is grown in many parts of the country, at both small and large scales. Whereas, tea is grown mainly in South-West and North-West of the country due to its special demand in climatic and soil conditions. Both tea and potato farmers are organized in cooperatives based on farms proximity and market structures (Rutunga et al. 2007; NISR 2019b). With setting priority crops and promoting the value chain approach as a strategy to enhance the agriculture sector performance, technology and innovation became a priority in commodities value chain activities. The development and application of new technologies to increase production and diversifying products are seen as key policy missions in Rwanda (MINAGRI 2018a). However, it remains a challenge to policymakers and other actors that are driving the development of the agricultural sector on how to set trajectories of technology and innovation in the sector. The main challenge is about how to establish operational networks that can allow stakeholders in the value chain to interact and to learn from each other and share resources.

In line with the above discussion, this paper explores the question of '*how are interactions organized among value chain actors for producing, transferring and using technology and innovation in the Rwandan agriculture sector?*' It does so by analyzing how value chain activities and actors' interactions are organized as well as modes of interactions for mainstreaming technology and innovation at different stages of the value chain. Two commodity value chains, namely potato and tea in the North-West region of Rwanda are used as case studies. The paper provides insights on how technology and innovation can be integrated into the agriculture system by using commodities value chains as a point of departure. This paper contributes to the ongoing debate on how a combination of value chains and innovation systems approaches helps to foster understanding of trajectories of learning and innovation in developing countries (Jurowetzki, Lema, and Lundvall 2018; Lema, Rabellotti, and Sampath 2018). Especially in developing countries, this is a living debate in the agriculture sector (cfr Juma 2015; Klerkx and Leeuwis 2008; Madzudzo 2011; Schut et al. 2015).

The rest of this paper is organized as follow. In the next sections, I provide a methodological framework used and present empirical findings that address the research question of this paper. I conclude with a discussion of findings and a conclusion on how value chains can be instrumental to the use of technology and innovation in the agriculture sector. The paper submits to the ongoing debate the view that value chains can be an option to set trajectories for technology and innovation in agriculture. Value chains have an appropriate structural organization for mainstreaming technology and innovation at different stages, and can also serve as a point of departure to build innovation systems in the agriculture sector.

Methodological framework

Data collection

In this study, both primary and secondary data were collected through semi-structured interviews and a structured review of official documents to address the main research question of this paper. Primary data were collected using semi-structured interviews with three main categories of actors. The actors' categories included public agencies, research and academic institutions and the private sector in the Rwandan agriculture sector. Public agencies included ministries and aligned agencies, whereas, research and academic institutions included universities and non-governmental organizations that are directly or indirectly involved in agricultural research. The private sector actors were composed of industries (agro-processors) and farmers; these were particularly from tea and potato value chains in the North-Western region of Rwanda. Interviewees were selected purposively and systematically based on their institutions, their position, seniority and experience. In government institutions, senior policymakers were interviewed. Senior researchers were interviewed in research and academic institutions, whereas cooperative managers were interviewed in farmers' cooperatives. For NGO and private sector, staff in decision-making positions were interviewed.

For each category of actors, an interview guide[1] was developed to guide an interactive discussion between the researcher and the interviewee. An interview lasted between 30 min to 1hour. During the interview, notes were taken and edited later for analysis. The interview guide had an introductory section with the purpose of the study and a request for consent. Prior to each interview, interviewees granted their consent for the interview. The identity of interviewees was kept anonymous and interview notes were handled with confidentiality, only researchers in the team had access to them.

Interviews were conducted from December 2018 to January 2019 with 20 interviewees (4 policymakers, 3 researchers, 8 farmers and 5 from industry). The main themes for interviews included actors' involvement in the value chain activities, sources of innovation and technologies, modes of collaboration among actors, resources allocation and major challenges for technology transfer and adoption. Data from these interviews were supplemented by data from a connected study to this on 'Construction of the National Innovation System in Rwanda: Efforts and Challenges (Yongabo and Göransson 2020).' Data from this study provided additional information on the overall innovation system at the national level and general possible interactions and facilitation mechanisms as well as efforts. These data were collected during the period of December 2017 to February 2018, with 24 interviewees involved in research management and decision making at national level. Primary data were complemented by secondary information from literature and public offices' reports.

Data analysis

Interview notes were organized for their analysis and presentation in a more comprehensive and informative way. A thematic analysis was used to analyze the text in order to respond to the research question of this paper. Text segments were extracted from notes according to main themes for analysis; common trends and differences in interviewees' responses were identified and synthesized. Themes (Table 1) were deducted from IS,

Table 1: Data acquisition and analysis

Data collection		Data analysis	
Primary data	Secondary data	Main themes	Key parameters
Semi-structured interview: Policymakers, researchers, private sector (farmers and processing industries) and NGOs.	**Document analysis:** Policies, programmes, strategic plans, official reports.	Mainstreaming technology and innovation in the value chain, interactions among value chain actors, technology and innovation trajectories in value chains.	Key value chain activities, value chain actors, level of interaction among value chain actors, driving factors for knowledge transfer in value chains, means/mode of interactions for knowledge transfer among value chain actors.

THM and Porters' Value Chain analysis model, as main analytical frameworks for this paper (Etzkowitz and Dzisah 2008; Lawton Smith and Leydesdorff 2014; Lundvall 2010; Porter 1985). Thematic analysis was used to explore on parameters of actors' composition, their activities, their complementarities and diversity, modes of interaction, capabilities, sources of innovation/technologies, potential or existing knowledge demand and supply, avenues of interaction, mechanism and facilitating tools for technology transfer and innovation.

Results

This section presents empirical findings from interviews and secondary information. The section is organized as follow: a) mainstreaming technology and innovation in the value chain activities and actors interactions. Entry points for technology and innovation in value chain activities and value chain actors' interactions and synergies creation are discussed here. b) Technology and innovation trajectories in value chains. Here, I discuss major driving factors for setting paths for technology and innovation in value chains and modes of interactions for knowledge use in value chains.

Mainstreaming technology and innovation in the value chain: Activities and actors interactions

Entry points for technology and innovation in value chain activities

Value chains are used as a policy instrument to develop the agriculture sector in many places. They are used to organize efforts for increasing productivity and profitability in agriculture. Agriculture value chains in Rwanda are generally acknowledged to be short with limited diversification in activities and products. However, they are important in the coordination of key activities that aim at improving the agriculture sector in Rwanda. Based on the value chain analysis conducted using Porter's approach (Porter 1985), as presented in Figure 1, there are '*primary and support activities*' in both value chains (potato and tea in the North-West of Rwanda). Primary activities include '*inbound logistic, outbound logistics, operations, marketing and sales, service and operations*'. The inbound logistics include mainly production activities such as land preparation, farm maintenance, crop protection and other associated activities. The outbound logistics activities mainly focus on harvest collection, processing, packaging and delivery. Marketing and sales activities are pricing, commercialization (including export), and communication-promotion and product diversification based on the market demand. Services are mainly agro-inputs delivery, extension services and training among stakeholders. Operations include standardization and certification, branding and records keeping.

All of these primary activities are supported by support activities that are connected to '*infrastructure development, human resource development, public procurement and technology and innovation development*'. The latter emphasizes agriculture technologies and innovation that address identified problems that affect the yield and quality of produces. Those problems are

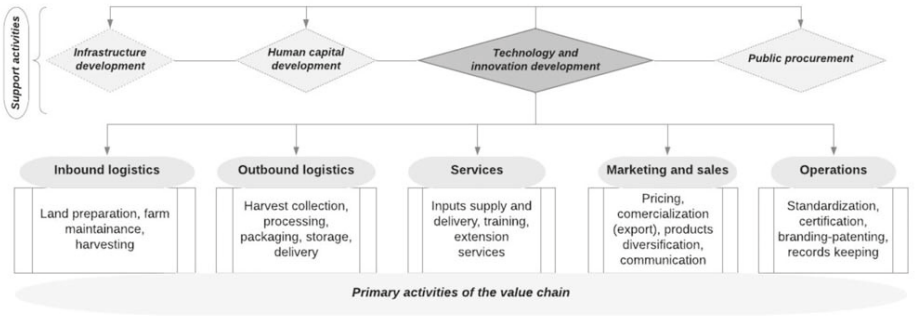

Figure 1: Mainstreaming technology and innovation in value chain activities.
Source: Author's compilation

mainly related to seed production, disease and pest control, fertilizers diversification and their application protocols and post-harvest management technics. Agriculture technologies development and innovation even though are seen as support activities in the value chain, they are key and crosscutting to all activities of the value chain, both primary and support activities. The structure of the value chain allows stakeholders to undertake innovation activities at different stages of the value chain depending on the need for value addition and profit maximization. However, this requires a strong interaction and separation of duties among actors and means to develop synergies and complementarities.

Value chain actors' interactions and synergies creation

Synergies among actors are imperative to maximize profit in the value chain. This can be achieved through collaboration among actors. The main actors in the two analyzed value chains (Figure 2) include farmers who are actively involved in inbound logistics (farm activities mainly) and processors who are engaged in outbound logistics (collection of harvest and post-harvest handling-processing). Government agencies and NGOs are mainly involved in operations and services. Marketing and sales activities are also mainly conducted by government agencies and processors. This is justified by the types of markets in the two value chains.

Potatoes are mainly produced for the local market composed of wholesalers and retailers in different parts of the country. The potato processing plant in the North-West of Rwanda is also a potential market for farmers. Under this market organization, both government and processors are involved in pricing in collaboration with farmers' organizations, mainly cooperatives. For tea, the main market is the international market for processed (semi-processed) tea. However, the tea factory buys the harvest from farmers. The tea factory sets the price for the tea harvest from the farmers, depending on tea price dynamics on the global market. Auction is the popular mode of selling the Rwandan tea at the international market. The interactions among these actors are not yet satisfactory for enabling actors to join efforts and use available capacities to maximize profit out of the use of technology and innovation. As highlighted by one of the interviewed processors:

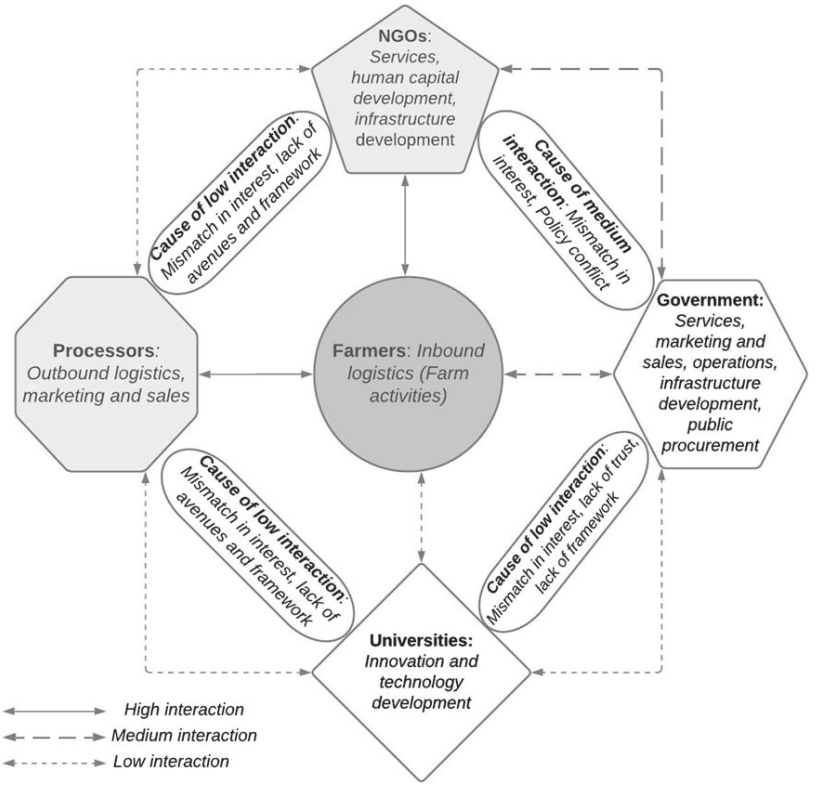

Figure 2: Main interactions among actors and their activities.
Source: Author's compilation.

> I wish that a lot can be done to boost innovation in the Rwandan agriculture sector. But I think the best thing to do is that stakeholders should focus on their core roles and interact for complementarity. Universities should accomplish their role of conducting research and producing the needed human resource. Whereas government agencies, like NAEB, should focus on the facilitation and assistance on issues related to exportation, training, organizing study tours, quality control, certification and standardization as well as associated updates. They should also facilitate the provision of certificates of origin and compensation for local habitat in case their goods are damaged to the expense of promoting market-oriented agriculture or infrastructure development (Processor, tea value chain).

The separation of duties among actors in the analyzed value chains was relatively clear. However, NGOs and public agencies have overlapping interventions in the primary activities that in some cases lead to duplications. To address this, there is a need for systemic and harmonized coordination. For support activities, universities were seen as a key actor in technology and innovation development. Infrastructure development remains the government's responsibilities and investors. The role of NGOs is considerable in the potato value chain compared to the tea value chain. This is explained by the nature of commodities; potato is more for subsistence whereas tea is business-oriented, which is not part of the primary interest of NGOs that are in most of the cases seen as charity organizations.

The role of universities and research institutions in technology and innovation production appears to be less satisfactory compared to expectations from both farmers and processors. There are few collaborative initiatives and there are no remarkable synergies among actors. It is hard to benefit from complementarities and maximization of resource exploitation in the two value chains. This also affects the value addition from technology and innovation as the main support resources. This highlights the need for avenues for interactions among actors to create synergies and complementarities, as pointed out by one of the researchers at the university:

> There is a need for intervention from different actors at all stages; this should start at least with people working together. The interventions should be characterized by complementarity among the value chain segments. Major among the interventions should focus on research, infrastructure, production, processing, policies and regulation. I think that cooperatives can be a good entry point in promoting innovation in the agriculture sector (University Researcher).

Technology and innovation trajectories in value chains

Major driving factors for setting paths for technology and innovation in value chains

There is a common view among interviewed stakeholders and from policy documents that technology and innovation are among major drivers for the agriculture sector development in Rwanda, and are a result of knowledge application for solving identified problems in the sector. However, dynamics in the production and use of knowledge for technology and innovation development may vary depending on various factors. Among major factors are the availability of resources (human and financial), infrastructure, nature of the problem, social structures, interactions as well as knowledge absorption capability of actors. Considering the Rwandan context with limited resources and insufficient infrastructures, it is not easy to rely on one form or source of knowledge for technology and innovation development. All respondents believed that innovation in the Rwandan agriculture sector should rely on the integration of research-based knowledge and traditional (indigenous) knowledge; this might be also supplemented by knowledge/technology importation (Figure 3). The importation of ready-made technology/knowledge is in many cases purpose-driven.

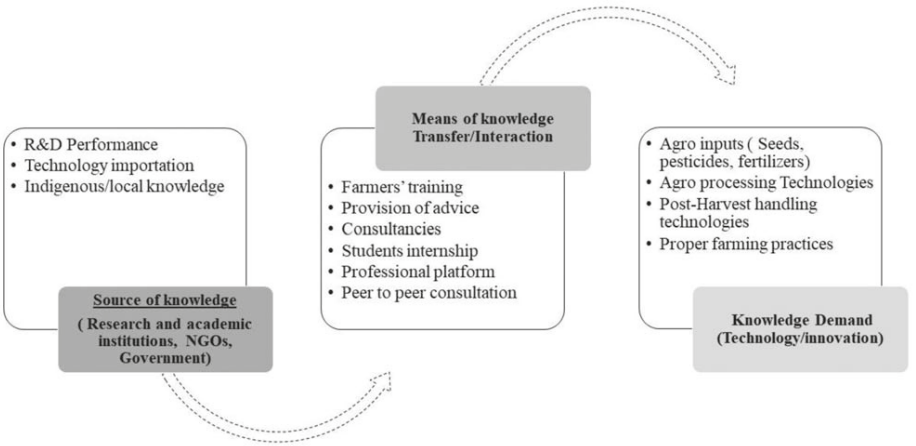

Figure 3: Sources of knowledge and means of interactions to meet the knowledge demands in value chains. ***Source:*** Author's compilation

Either driven by the cost, consumers' preference or specific market demand and performance.

The consideration of research-based knowledge as a priority by many of the interviewed actors (mainly industries and policymakers) emphasizes the need for designing fit-for-purpose research interventions that address real problems in the sector, in the Rwandan context. Proper diagnosis and understanding of major issues in the Rwandan agriculture context were highlighted by interviewees as the entry point for innovation development in the Rwandan agriculture sector. This can set a path for finding appropriate solutions that address complex problems in the sector. However, this appears to be one of the major problems for research-based knowledge production in the Rwandan agriculture sector. Current research efforts are alleged to pay more attention to basic knowledge instead of producing applied and technological knowledge that responds farmers' problems.

From that point of view, there is a quest for practical and transferable knowledge that addresses critical issues faced by technology and innovation end users. Despite the high consideration of research as the key source of needed knowledge, there is a shared view among actors that the research capacity and research outputs are still very low. In addition to this, the dissemination of the little available research outputs is still challenging and hard to establish. Among the underlying reasons for the weak dissemination and uptake of the available research outputs are the limited absorptive capacity of end-users (mainly farmers) and the lack of appropriate tools and structures to overcome that absorptive capacity barrier. The use of appropriate tools that match the learning capability of farmers is still a challenge, as mentioned by one of the cooperative leaders:

> Most of our cooperative members have finished primary school and others did not even go to school. It is hard to convince them to adopt new technology and to teach them how to use it. Most of them cannot even use the technical documents that are given by our partners, like NGOs or RAB (President of potato growers cooperative)

Modes of interactions for knowledge use in value chains

In this section, I provide perceptions from actors in tea and potato value chains on aspects of application of knowledge for a better performance of these value chains, and opportunities and challenges that can be taken into account in the process of facilitating the use of knowledge for technology and innovation development in the Rwandan agriculture sector.

Perceptions from the potato value chain: Based on problems in the potato value chain, both scientific and traditional (indigenous) knowledge have the potential to provide needed solutions. As mentioned by the farmers, major areas for knowledge and skills demand are: farming practices, pests and diseases control, seeds improvement, soil conservation and management and post-harvest handling. Mainly NGOs and farmers' federations are actively engaged in addressing that demand, where farmers are trained in different aspects related to proper farming practices, farm management and cooperative management. In addition to training, other technical supports are provided as well as facilitation for study tours. Farmers expressed high expectations on research and academic institutions. Unfortunately, the current situation shows (Figure 2) low interactions for knowledge sharing/transfer between the academic institutions and other actors in the sector.

There are emerging signs of willingness and efforts to materialize the farmers-universities relationship. This was realized through the case of potato seeds problem, where research and academic institutions in the North-West region of Rwanda collaborated with farmers to provide some solutions. The university conducted research on suitable potato seeds and provided cultivars to seed multipliers. This was appreciated by farmers. In addition to this, more initiatives are emerging, where universities provide advice to farmers and help them to meet the factory quality and safety standards. In most of the initiatives, practical knowledge and technical skills are offered and solicited. This emphasizes the importance of focusing on applied agricultural research. The consideration of traditional knowledge in producing scientific knowledge might be of capital importance as it offers opportunities for relevancy and easy adoption of research outputs by farmers, as they feel that they have contributed to the research outputs.

Processors also expect to acquire the needed knowledge and technologies from universities and other Research and Development (R&D) organizations. This is also due to the lack of R&D units in industries in the potato value chain. The consulted factory during the study relies mainly on technology importation from the Netherlands, mainly due to their established network with the Dutch peers. The factory expressed worries about locally developed technologies in terms of quality and standards. However, the factory believes that there are issues that can be addressed by research that is being conducted at local universities in Rwanda. Generally, there is low recognition of public agencies in providing technical assistance to industries in the potato value chain, while farmers are getting that assistance from public agencies. The role of universities and public agencies should be enhanced in the production and use of knowledge for technology and innovation development in agriculture, as mentioned by one of the potato processors:

> Universities should conduct researches that are responsive to the private sector demand and should do timely dissemination of their research outputs so that companies can access the new knowledge while fresh. The government should consider investing in agriculture and not leaving this to the private sector, which is not even secure in investing in the agriculture sector in Rwanda given the constraints related to climate change, soil fertility and other environmental related issues. There is no strong insurance scheme for agriculture/farming business in Rwanda, and yet this can be one of the solutions in risk-taking for innovation. Better access to finance need to be facilitated as well. (Factory Owner)

Perceptions from the tea value chain: The tea value chain being more business-oriented, actors expressed a high need for technological knowledge for product

diversification and value addition. Processing technologies and technics are major forms of needed knowledge in factories. Tea growers are interested in good farming practices, harvesting technics and good agro-inputs. Tea varieties diversification is also among the top needs of both growers and processors, as current varieties are criticized to be old; this has a considerable impact on the quality and performance of tea products on the market. These needs are expected to be addressed through research conducted at universities and other R&D organizations. For technologies that cannot be produced in Rwanda, processors expect the Rwandan National Agriculture Export Board (NAEB) to facilitate in acquiring them by means of technology importation.

The consulted factory was interested in students' internships as a means of using the knowledge that students acquire at the university. They also consider research-based consultancies as another way to channel the generation and sharing of knowledge between industries and universities. Some works have been done in this framework, like technical assistance in soil sampling and analysis. Another alternative source of knowledge that the factory is interested in is the tea professionals' platform. The platform is interactive but it is still at the early stage and needs to be sustained. With this platform, professionals share experiences and challenges that they face in their daily work. This allows them to join forces and share knowledge to find solutions through peer-to-peer consultation. This can be one of the ways to sustain knowledge use in the value chain, in case key actors are interested to join forces to institutionalize the platform and make it a dynamic institution with regular practices with all the needed support. This shows that interactions among actors for sharing resources, skills and promoting research activities that are responsive to key problems in the value chain should be the central point for promoting technology and innovation in the Rwandan agriculture sector, as highlighted by processors in the tea value chain:

> There is still a lot to be done to increase the innovation propensity in the Rwandan agriculture sector. First of all, there is a need to conduct enough research to address issues in the value chain and the government should play a central role in this. RAB and NAEB are supposed to contribute to this, but so far, it is not clear how they contribute and the solutions that they are providing to farmers. NAEB produces policies but how are they contributing to innovation development? Local industries are not much interested in investing in R&D because they have limited capital and it is not clear to them how this investment can contribute to their business development. (Factory Manager)

Discussion

Based on agriculture value chain activities and actors' interactions, technology and innovation can be mainstreamed at all stages of the value chain. This might be done through 'upgrading' in different dimensions, which is the ultimate goal of the value chain approach. Upgrading for agriculture value chain actors means improving farming and business skills in ways that allow them to capture more of the value in the value chain. Upgrading can increase benefits and/or reduce risks for value chain actors. The upgrading process is based on interaction among actors for learning new skills and adopt improved practices. This can be for process, function and coordination (Cuddeford et al. 2013; Gibbon 2003). Technology and innovation are important for process upgrading in agriculture value chains for improving production processes (better planting materials, irrigation, better pest and disease control technics, etc.), post-harvest handling technics and better marketing. In addition to upgrading, technology and innovation can facilitate coordination among actors by providing efficient communication tools and better service delivery tools. In the context of Rwanda, with upgrading in value chains, technology and innovation can lead to value chain specialization. This is one of the main policy goals for the Rwandan agricultural sector transformation, from subsistence to market orient agriculture. The sequence of value chain activities provides a better structure for adopting different types of technology and innovation at different stages. However, this requires high interactions and synergies among actors at different stages of the value chain.

Complementarities and synergies among actors result from interactions that aim at mutual support to meet a collective interest. In places where interactions are low, innovation propensity is low and it is hard to realize systemic approaches for innovation (Madzudzo 2011; Weyori et al. 2018). For the case of the two analyzed value chains, there are low interactions among farmers and universities. This is mainly due to the lack of shared interest and lack of trust. There is also a lack of appropriate institutional frameworks that stimulate interactions. In places where this relationship (university-farmers) exist, specialized funding instruments and specific policy actions are used to establish and exploit interaction between these two actors. Another underlying reason for low interactions in the two cases but also shared in many agriculture innovation systems in Africa is the mismatch between the knowledge supply and knowledge demand. One option to address this is to introduce the innovation brokering functions to ensure the matching between the knowledge demand and supply. According to Klerkx and Leeuwis (2008) and Madzudzo (2011), innovation brokers can be catalyst individuals or organizations that can articulate the knowledge demand to match the supply or vice-versa. This also can be done by creating networks that help actors to harmonize their interests.

Due to the mismatch between the knowledge demand and supply, in both value chains (tea and potato), knowledge transfer is still a challenge. To address this, there is a need for interactive learning relationships that allow mutual learning to occur. Lundvall (2010) and Jensen et al. (2016) suggest the 'Doing-Using-Interacting' mode of learning as a suitable mode of learning for mutual learning among actors in innovation systems that are not well established, with low R&D capacity. This mode is mainly based on the use and exchange of tacit knowledge, which builds on experience sharing and informal interactions among actors. Considering the Rwandan agriculture sector, this mode of learning can help to respond to the needs of farmers, as they need contextualized technologies that consider the integration of their

traditional knowledge/technologies. Hence, it is important to rethink strategies for knowledge production and transfer in the Rwandan agriculture sector. Ngaboyisonga et al. (2014) suggest the shift from conventional research to participatory research. However, based on empirical evidence in this study, it was observed that this shift needs to be institutionalized and embedded into social structures, mainly including farmers at the early stage of research and engaging them as much as possible so that they feel their importance in the process and own the outputs for implementation. This concurs with Schut et al. (2015) and Mytelka's (2016) suggestions about the social inclusivity of innovation and development strategies for the agriculture innovation system in sub-Saharan Africa.

From this study, interviewees highlighted that lack of trust and leadership among actors, lack of financial capacity, low technological absorptive capacity, mismatch in interest, lack of avenues for interaction and lack of ownership are major underlying reasons for low interactions and key challenges for knowledge transfer. According to Adam et al. (2018), innovation platforms were introduced in Rwanda to deal with these issues and facilitate inclusivity as well as benefits sharing among actors. They have been tried in different value chains, such as irish potato, maize and cassava. However, their level of success was different across regions in Rwanda. For failed innovation platforms, the above reasons were among the root causes. Whereas for successful Innovation Platforms, they acknowledge the role of cooperatives as good channels for interaction and source of leadership as well as organization and harmonization of activities and interest among members of innovation platforms. Thus, it might be reasonable to learn from success stories under the cooperative schemes for the integration of technology and innovation in agriculture. Moreover, the sustainability of innovation platforms needs to get full attention for building a functioning agriculture innovation system. The performance of innovation platforms also varies from one value chain to another and from one type of innovation to another. Innovation Platforms can be among the options to organize interactions among value chain actors within the agriculture innovation system.

Conclusion

This paper explored how value chain activities and actors' interactions are organized for producing, transferring and using knowledge for technology and innovation development in the agriculture sector in Rwanda. By doing so, it contributes to the ongoing debate about how a combination of value chains and innovation systems approaches helps to foster understanding of trajectories of learning and innovation in developing countries, particularly in the agriculture sector.

Empirical findings from this study showed that agriculture commodities value chains offer a structure that can serve as a point of departure for integrating technology and innovation in the agriculture sector. Technology and innovation are essential to all value chain activities and can be mainstreamed at different stages of the value chain. However, this can only be accomplished if there are strong interactions and synergies among value chain actors. In the analyzed value chains, interactions are generally low between universities and other actors. Achieving strong interactions and synergies might require the use of facilitating tools to stimulate and sustain interactions among these actors, like innovation platforms and innovation brokering as suggest by Adam et al. (2018) and Klerkx, Hall, and Leeuwis (2009). This can be applied in the framework of THM. These tools have the potential to stimulating trust, policy coherence, knowledge sharing and efficient allocation and use of resources, if well applied. These tools do not exclude the use of conventional extension techniques; however, they can supplement them and fill the gaps identified in conventional extension services due to the complexities of the problems in the agriculture sector.

Moreover, mainstreaming technology and innovation in value chain structures requires a holistic approach with systemic thinking and actions. A combination of value chains and innovation systems is one of the options that can be explored in this case. Innovation systems can be based on specific technologies, products or regions. The above-suggested tools can serve as instruments to connect value chain patterns to innovation systems components. The application of these tools also might require sustainable mechanisms for human capacity building, for both knowledge producers and knowledge users. Financial capacity and infrastructure are other needed capacities to provide a proper operational environment. Strong collaboration among institutions and harmonized policies and their instruments are key pre-requisite conditions to build these capacities and sustain the value chain-innovation system nexus in the Rwandan agriculture sector.

Based on empirical evidence and conducted analysis, it is concluded that value chains are among the best options to provide structural organization to set trajectories for technology and innovation in the agriculture sector. However, value chains need to be associated with other operational tools and frameworks such as IS and THM. One option to explore for the contextualization of these frameworks is to analyze how major functions like learning and wealth creation can be accomplished and how they fit into a specific context. In the Rwandan context, it was observed that 'knowledge brokering' can be explicitly defined as a function that can facilitate learning. It is recommended for further research to explore how value chains can be connected to innovation systems, taking into account different boundaries and levels of analysis.

Note

1. Interview guides are provided as annexes to this paper.

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Annex I: Interviews guides used in primary data collection

Interview guide for Rwanda for round 1 (December 2017 to February 2018): Key actors (Policymakers, researchers and private sector)

Initiating questions/Points of discussion
1. Are you familiar with the National Innovation System (NIS) concept in your institution? If Yes, what are your views on it?
2. What do you consider as innovation and what are forms of innovation that your institution is interested in?
3. What is your view on how innovations emerge and are disseminated?
4. What are your views on the role of Innovation in achieving the national economic development goals?
5. How do you view the policy and legal frameworks in promoting innovation for development?
6. What socio-economic sectors innovation can contribute the greatest to economic transformation or development goals?
7. With whom does your institution work with for research and innovation matters?
8. How is research and innovation managed in your institution?
9. How does your institution promote the move from research to innovation?
10. What are funding mechanisms for Research and Development (R&D) in your institution?
11. What are mechanisms for funding Innovation activities in your institution?
12. How does your institution facilitate (get involved in or support or promote) the move from Innovation to entrepreneurship?
13. What factors do you think are hindering or slowing the move from innovation to entrepreneurship?
14. What are mechanisms for capacity and competence development for innovation available in your institution?
15. What is one strategy that you think could boost research and innovation uptake in Rwanda?
16. Concluding statement: Is there anything you wish to be done in the future to improve the performance of your institution in R&I promotion and Rwandan NIS development in general?

This interview guide was used in Yongabo and Göransson (2020), a study connected to this paper.

Interview guides for round II (December 2018 to January 2019):

(1) Interview guide for policymakers and researchers in the agriculture sector

Initiating questions
1. What types of innovations do you think are promising in the Rwandan agriculture sector?
2. What do you think are the factors leading to these types of innovations or decision to innovate?
3. How do you find government policies and strategies enabling for innovation development?
4. Who do you think are the key actors to boost innovation in the Rwandan agriculture sector?
5. What do you recognize as major forms of interaction (collaboration frameworks) for these actors?
6. What is the form of knowledge that you consider most important in contributing to innovation development in the Rwandan agriculture sector?
Concluding statement: Is there anything you wish to be done in the future to improve innovation propensity for the actors in the Rwandan agriculture sector?

(2) Interview guide for farmers and processors

Initiating questions/Points of discussion
1. What types of innovations do you think are promising in the Rwandan agriculture sector?
2. What do you think are the factors leading to these types of innovations or decision to innovate?
3. How do you find government policies and strategies enabling for innovation development?
4. What is the form of knowledge that you consider most important in contributing to innovation development in the Rwandan agriculture sector?
Specific for the value chain
1. How do you generally describe the potato/tea value chain in Rwanda?
2. How do you perceive the current industrial development in the value chain (Potato/tea)?
3. What are the major products (tea/potato) and their targeted market?
4. What are the driving factors for your products specialization/ new product development
5. How do you select your technologies to be used in the innovation process?
6. Where do you acquire your technologies and other needed skills to innovate
7. What are your considerations in technology selection?
8. What are your considerations in technology adoption?
9. How is your personnel ready to adopt new technologies?
10. How do you access the new technologies?
11. Who pays (cover the cost) of the new needed technologies
Concluding statement: Is there anything you wish to be done in the future to improve innovation propensity for the actors in the Rwandan agriculture sector?

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