SCHOOL OF
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Sustainable Cattle Production in Brazil

The Agricultural Innovation System of Integrated Livestock Systems in Mato Grosso State

by

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Abstract

The precarious state of affairs in the Brazilian Amazon rainforest, particularly in Mato Grosso, where unsustainable cattle ranching is driving the deforestation. Brazil needs to invest in sustainable development of its cattle production. Integrated Livestock Systems is a technology which serves this purpose, but is poorly integrated into Brazil's Agricultural Innovation system. The literature review found that overall the Agricultural Innovation system of Mato Grosso involved in Integrated Livestock Systems innovation is highly diversified, with a wide range of actors in the public, private and NGO sectors, with collaboration between stakeholders across the Agricultural Innovation system. Yet, there are still challenges to innovation capacity, especially in research, knowledge-sharing, education and training, funding and infrastructure, where small farmers form the frontier of Integrated Livestock Systems innovation and adoption. The Agricultural Innovation system framework is designed to apply an analytical framework to information from available empirical material, such as earlier studies exploring science, technology, and innovation policy issues in the sector, in order to determine linkages and interactions between actors within and across domains, as well as institutions and policies which constitute the enabling environment for innovation. The intervention framework then diagnosed current and required capacities for facilitating innovation, with which it suggested principles and options for policy interventions. Most mechanisms that work to support the innovation of Integrated Livestock Systems are already in place, but remain have many challenges. Interventions were suggested to expand the existing mechanisms that supported innovation, focusing on increasing multi-stakeholder collaboration in areas such as research, knowledge-sharing, education and training, and funding, while focusing support away from cattle ranching.

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1 Introduction

1.1 Research Problem

In 2020 the rate of *deforestation* of Brazil's Amazon reached the highest level since 2008 (Statista, 2020). Models find that the deforestation may be approaching a "tipping point", after which a self-perpetuating collapse of the region's biodiversity and ecosystems will lead to large-scale savannah or desertification of the Amazon, with catastrophic consequences for the world's climate (Nobres et al). The Amazon rainforest influences global rainfall regimes, the loss of which will would lead to more intense droughts, and reduced agricultural yields far beyond regional boundaries (Carrero et al, 2020). By 2018 around 17% of the Amazon rainforest has been destroyed, with some models suggesting that reaching a 20–25% threshold may trigger an unrecoverable collapse of the ecosystem (Lovejoy et al, 2018). Following current agricultural trends, this tipping point could potentially be reached in only 15–30 years (Carrero et al, 2020).

On the other hand, at the expense of the Amazonian destruction Brazil has become a leading exporter of agricultural products, with the agricultural sector being a major source of socio-economic development (Stabile et al, 2020). The deforestation of Brazil's Amazon has enabled the country to become the largest exporter of beef in the world, exporting 2.7 million metric tons in 2020 (Statista, 2021), with the Brazilian cattle herd increased by more than 100% between 2000 and 2015 in response to increasing global trade of beef. However, much of this increase has taken place in the Amazon: 75% of the national herd increase occurred within the Legal Amazon, particularly in the state Mato Grosso, which is the de-facto hub of cattle ranching, and is primarily characterized by large-scale agriculture and pasture extensification (Caviglia-Harris, 2018). In theory, Brazil could meet the world's demand for beef until 2040 without further deforestation by increasing its cattle productivity on existing pastures, however, the productivity of Brazilian beef production is very low, especially in Mato Grosso, where pastures are producing beef at only a third of the sustainable potential (Zu Ermgassen, 2018). Conventional ranching systems degrade pasture lands after a year, whereafter further deforestation is needed for new pastures. A significant share of the existing pasture land is already classified as degraded and is unused, yet around 11 million hectares of such degraded land in the Amazon could be recovered in 12 months by using sustainable beef production systems (Arias et al, 2017; De Waroux et al, 2019).

The Sustainable Development Goals and the Paris Agreement from 2015 highlight the need to improve agricultural practices in the Brazilian Amazon, as growing populations needs food while arable land is being degraded. Thus, the agricultural sector is under pressure to find a sustainable way of meeting the world's demands for beef (United Nations, 2015a; 2015b).

To this end *Integrated Agricultural Production Systems* are an old innovation which offer a sustainable alternative to the mainstream agriculture practices in the Brazilian Amazon. Variations of *Integrated Agricultural Production Systems* include cattle production in a sustainable agriculture system, and are of interest to reducing the deforestation in Mato Grosso. These allow the incorporation of technologies consisting of continuous cultivation of different crops (and sometimes forest) in rotation and combination with forage and grazing livestock, using no-till farming, to increase crop productivity, the availability of labor force all year round, and the income and quality of life of rural producers (Embrapa, 2021). The different variations of Integrated Agricultural Production Systems which include livestock all serve the function of reducing the deforestation pressure of cattle production, and due to their overall similarity they can be grouped under the term *Integrated Livestock Systems (ILS)* for the purposes of this thesis.

Compared to the unsustainable continuous expansion of conventional cattle ranching practices, ILS initiatives in Brazil have successfully combined cattle grazing and pasture recovery with sustained agricultural yields higher than the national averages, providing farmer's with security of multiple output possibilities, increased employment opportunities, and conservation benefits (Brienza et al, 1991; Nair, 1991; Yamada et al, 2002; Blinn et al, 2013; Latawiec et al, 2017; Caviglia-Harris, 2018; Villa et al, 2020; dos Reis et al, 2021). Considering the context of unsustainable cattle ranching in the state of Mato Grosso, finding ways of expanding its beef production by recovering degraded pastureland with ILS may be the most sustainable solution. ILS have long been the basis of agriculture in a wide range of environmental, social and economic conditions around the world, already accounting for around 75% of the milk, and 60% of the meat consumed by poor people in the world. In the past ILS systems were a staple of agriculture in Brazil, however, in the 1970s and 80s many farmers in Brazil abandoned ILS as the government promoted modernization of the agricultural sector and individual cash crops. Yet, since the 1990s the use of ILS appears to be increasing, albeit slowly (Garrett et al, 2017a).

The innovation of ILS is still a minor element of Brazil's *Agricultural Innovation System* (AIS), arising mostly from individual farmers' experimentations or internationally funded initiatives, and other development projects, research initiatives, education and training programs (Nair, 1991; Porro et al, 2015; Futemma et al 2020; Villa et al, 2020). Since the 2015 Paris Conference of the Parties, Brazil committed to combat illegal deforestation and facilitate 12 million hectares of reforestation by 2030 (Lovejoy et al, 2018) and through various public and private policies the annual deforestation in the legal Amazon fell overall by >70%, while beef production increased by 72% between 2004 and 2017. (Stabile et al, 2020). However, regulations have often been weak or contradictory, and thus deforestation has begun rising again since 2012 (Arias et al, 2017; Carvalho et al, 2019). Brazil's 2009 government and large landholders and their representatives have initiated new measures that threaten the Amazon environment, as well as global climate. These include weakening Brazil's environmental agencies and laws which previously regulated deforestation and reforestation, but now grant amnesty to deforestation, approve unsustainable agricultural practices, and deny climate change. (Ferrante et al, 2019; Azevedo-Ramos et al, 2020; Silva Junior et al, 2020). The drastic situation in the Brazilian Amazon, particularly in Mato Grosso, and the recent political changes in Brazil, highlight the need for an investigation into Mato Grosso's AIS in order to identify the obstacles and opportunities with the aim of intervening in the innovation and upscaling of ILS practices.

1.2 Aim and Scope

Considering the precarious state of affairs, the aim of this thesis is to examine the prospects and obstacles faced by the innovation of *Integrated Livestock Systems* in Mato Grosso, Brazil. Specifically, it investigates how Mato Grosso's AIS has impacted the innovation of ILS by analyzing the different domains involved in ILS in Mato Grosso through the AIS framework. Based on these findings, interventions for scaling up the innovation of ILS are then suggested. The geographic scope of this thesis is mainly focused on ILS initiatives in Mato Grosso state, which have seen extensive increases in deforestation related to the expansion of cattle ranching, and is thus prime targets for rehabilitation of degraded pasture land via implementation of ILS. The temporal scope of the study covers mainly recent developments of the AIS and its impacts on the innovation of ILS, which is necessary for the analysis to suggest suitable interventions.

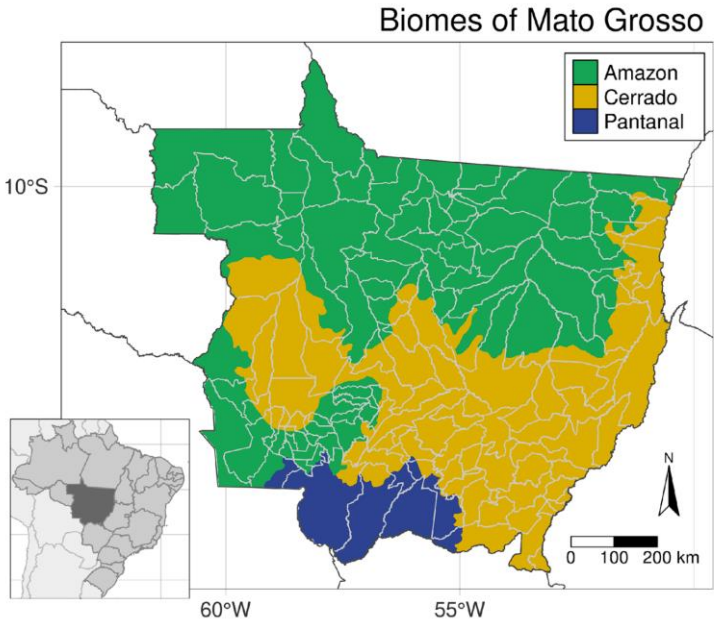

Figure 1. Map of Mato Grosso, Brazil with biomes. Adapted from Kusching et al (2021).

1.3 Outline of the Thesis

The following chapters, Chapter 2 covers the theoretical background for the AIS framework, its applications and a literature review of recent research on ILS innovation in Mato Grosso. Chapter 3 covers a presentation and examination of the sources of data used for this thesis. Chapter 4 presents the methodology of how the AIS framework is applied to the analysis, specifically on the application of the analytical framework to code the literature review data and the intervention framework to diagnose the capacities for facilitating innovation of the AIS in order to suggests principles and options for interventions to strengthen innovation capacity. Chapter 5 covers the analysis of applying the intervention framework to the findings from the application of the analytical framework to the literature review. Chapter 6 concludes the results.

2 Theory

2.1 Theoretical Approach

This section introduces the core concepts of the AIS theoretical framework, as well as the historical and theoretical justifications for the application of the AIS framework to this thesis. The methodology of applying the AIS framework to the analysis will be explored in Section 4.

The World Bank (2006) presents an operational *Agricultural Innovation Systems* (AIS) approach as an extension of the *Innovation Systems* (IS) concept, an analytical framework which assesses the agricultural IS of developing countries and identifies useful interventions. Figure 2 portrays a model of the IS developed by Arnold and Bell (2001). The IS concept does not only concern itself the suppliers of science, but extends its focus to include the demand for knowledge inherent in the interactions of actors involved in innovation. An IS can be defined as networks of organizations, enterprises, and individuals that work together to bring new products, processes, and forms of organization into socio-economic use, where the behavior and performance of these networks are affected by institutions and policies. The IS focuses specifically on the factors which affect the demand for and use of knowledge, and thus concerns not only the suppliers of science, but the totality of interaction between actors involved in innovation.

The IS concept is derived from direct observations of countries with strong innovation records, and has mainly been used to explain patterns of economic performance in developed countries. However, IS has received little focus as an operational tool for improving a system's capacity, and has only recently been applied to analyzing agricultural innovation in developing countries. Seeking to assess the usefulness of the IS concept in guiding investments to support the development of agricultural technology, the World Bank (2006) thus developed the AIS framework as an operational extension of the IS concept via a comparative case study analysis of agricultural innovation in select developing countries. While investing in science and technological capacity is still important to innovation, the AIS framework adds additional insights and interventions to the IS concept in order to influence the creation and the use of science and technology for economic development. Thus, the AIS allows for a deeper understanding of how to designing interventions for a developing country's agricultural sector to better create and make use of new knowledge which goes beyond merely investing into R&D.

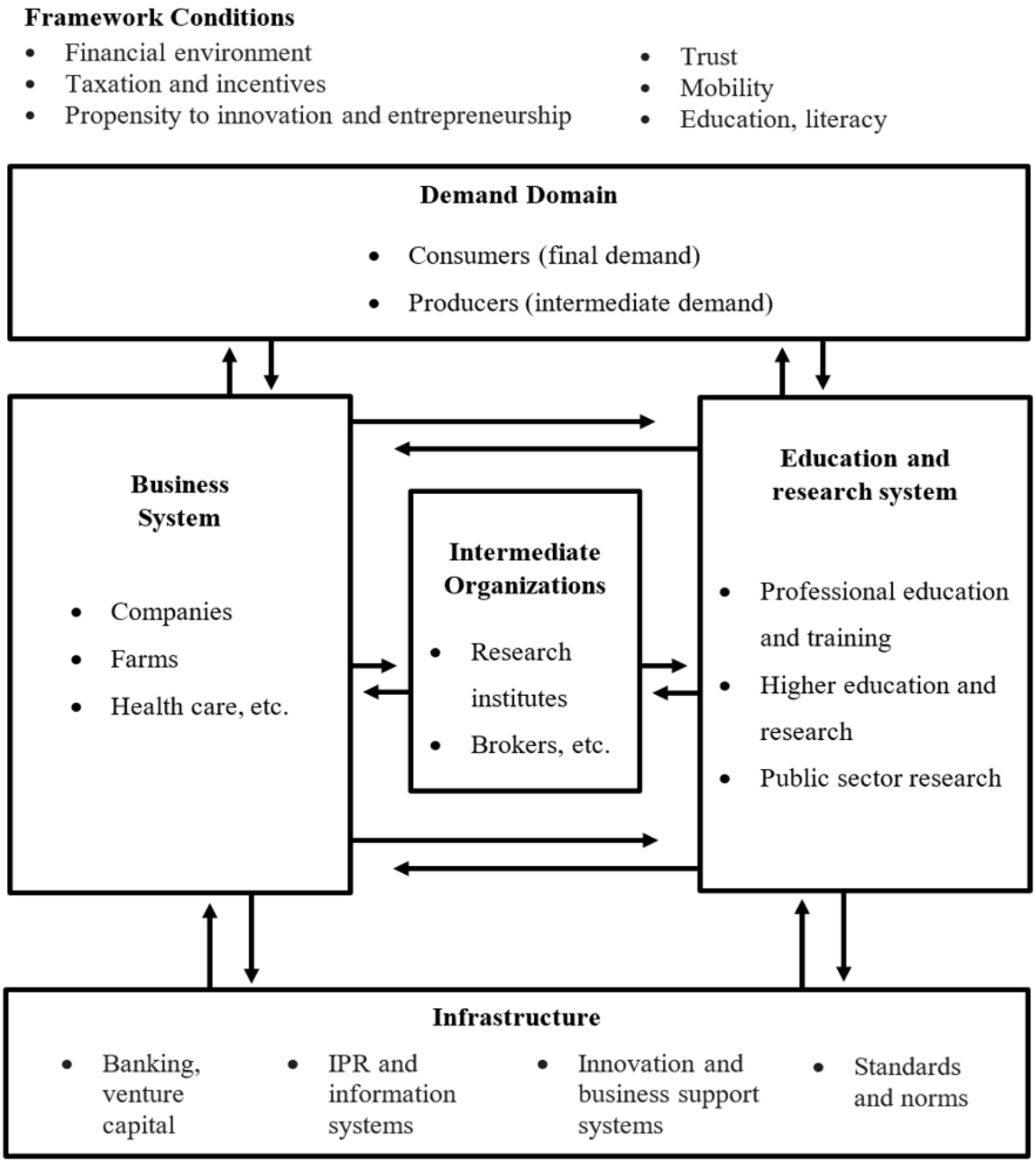

Figure 2. Elements of an Innovation System. Adapted from Arnold & Bell (2001).

Similar to IS, shown in Figure 2, the AIS framework, shown in Figure 3, concerns the interactions of individuals and organizations with different knowledge within a social, political, policy, economic, and institutional context. The AIS framework consist of five main domains, which are useful for identifying organizations and individuals relevant to the agricultural sector: *(1) The enterprise domain* of firms and farmers using codified and tacit knowledge, as well as producing some tacit knowledge. *(2) The research domain* of formal research organizations producing codified knowledge, mainly the public sector, with smaller private sector and NGOs. *(3) The demand domain* of consumers and domestic and international markets for products, including policy actors demanding knowledge and information. *(4) The intermediary domain* of organizations which ensures that knowledge flows between the different parts of the system. *(5)* Finally, different *support structures* which dictate the possible systemic interactions.

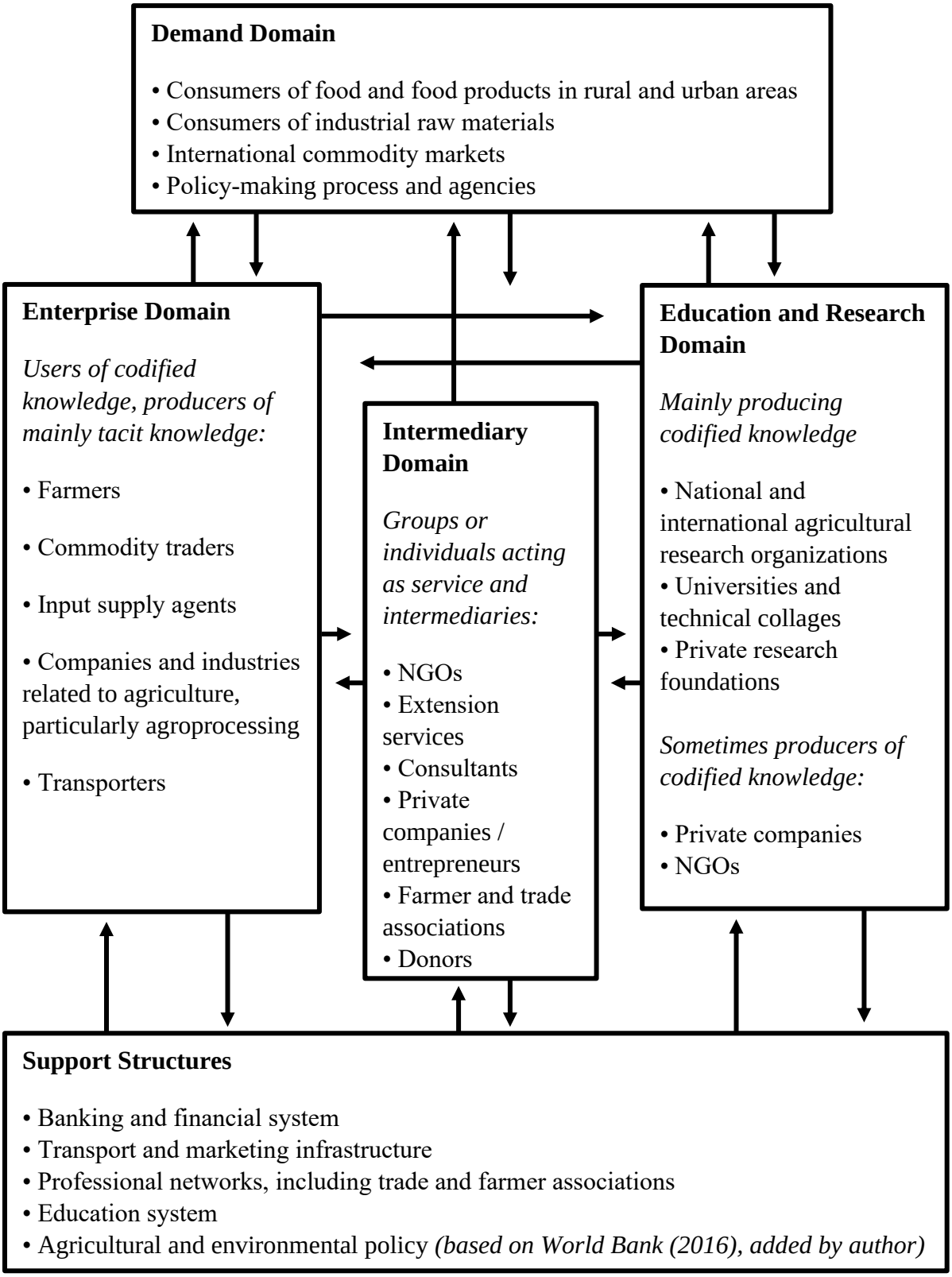

Figure 3. Elements of an Agricultural Innovation System. Adapted from World Bank (2006)

The AIS framework thus shapes the analysis of agricultural innovation in developing countries. By utilizing the checklist of an *analytical framework* to investigate the interactions in the IS, these findings can be applied to an *intervention framework* of innovation typologies and diagnostic features to assess the system's innovation capacity, which based on guiding principles can finally be used to identify potential interventions for the given innovation system.

2.1.1 Development of the AIS Framework

As the context of agricultural development has evolved, so has the idea of "research capacity" developed along with different approaches towards investing in a system's capacity to innovate. Most previous national-level strategies to promote sustainable agricultural development have focused on investments in knowledge via science and technology, and many being successful. The National Agricultural Research System concept in the 1980s focused on strengthening research supply by developing national infrastructure, capacity, management, and policies (International Service for National Agricultural Research, 1992). Later in the 1990s the Agricultural Knowledge and Information System concept recognized that research supply was not the only means of generating or accessing knowledge, and thus extended its focus to links between research, education, and extensions to the demand for new technologies by farmers (Food and Agriculture Organization, and World Bank, 2000). More recently, research has focused on demand for research and technology in developing the Innovation Systems concept, as strengthened research systems alone can increase supply of new knowledge and technology, but may not necessarily be successful in improving the capacity for innovation throughout the agricultural sector (Organisation for Economic Co-operation and Development, 1997).

Therefore, the World Bank (2006) aimed to examine the reasons behind the shortcomings of the IS concept in fully comprehending the development of innovation in the agricultural sector. Thus, via a comprehensive historical literature review of agricultural research ranging from 1961–2001 the study was able to identify six changes in agricultural development which highlight the need to re-examine how innovation occurs within the modern agricultural sector: *(1)* Markets, not production, is increasingly becoming the driver of agricultural development; *(2)* The environment of production, trade, and consumption for agriculture and its products is increasingly becoming more dynamic and its development is evolving in unpredictable ways; *(3)* Knowledge and technology is increasingly being created and diffused in the private sector; *(4)* Growth in information and communications technology has increased exponentially and transformed the ability to take advantage of knowledge developed in other places or purposes; *(5)* The knowledge structure of the agricultural sector in many countries is changing noticeably; *(6)* Lastly, the development of agricultural is increasingly taking place in a globalized setting. Modern agricultural development thus largely depends on how successfully knowledge is generated, diffused, and applied in the system, and new perspectives on the agricultural innovation process of were needed to yield practical approaches to agricultural development.

Seeking to assess the usefulness of the IS concept in guiding investments to support the development of agricultural technology, the World Bank (2006) developed the AIS framework as an operational extension of the IS concept via a comparative analysis of eight case studies which captured the elements of elements of the dynamic context of agricultural development: *(1)* Containing niche sectors which have previously been showing strong patterns of growth; *(2)* Containing sectors which have been comprehensively integrated into the global markets; *(3)* Containing traditional sectors which are being transformed by the growth of upstream activities of the food chain, highlighting implications of the industrialization of the food chain; *(4)* Containing sectors which are providing extensive employment opportunities for the poor. The following case studies were analyzed: Medicinal plants and vanilla production in India; food processing and shrimp production in Bangladesh; cassava processing and pineapple production in Ghana; and finally cassava processing and cut flower production in Colombia.

To facilitate the comparative analysis of the innovation systems in the different case studies, the World Bank (2006) extended the IS concept by developing an AIS *analytical framework* with tools to explore partnerships and organizations in their dynamic agricultural contexts. Applying the framework to conduct a comparative analysis of the case studies revealed that the linkages for creating dynamic systems of innovation were frequently absent in the system. Especially attitudes and practices of system actors were often major obstacles to innovation, and competitive markets exposure was insufficient in incentivizing new collaboration patterns. The lacking interactions created a limitation of access and demand for new knowledge, research, technological and organizational learning, as well as sources for financing innovation, resulting in weakened sector upgrading and integration of social and environmental concerns. From the comparative analysis it was found that research plays an important role in agricultural innovation, but is not always central. The public sector and an enabling environment are key players, as competitiveness depends on collaboration for innovation, and the market is not sufficient to promote interaction. Interventions are essential for building capacity and learning to react to competitive challenges, and must integrate social and environmental sustainability to achieve economic success. Organization of rural stakeholders is central to innovation system development, but actors that are critical for coordinating the sector's innovation systems are either overlooked or missing. Finally, a wide set of attitudes and practices must be cultivated to foster a culture of innovation. These findings clarified the nature of innovation capacities in the modern agricultural context, the insights from which guided the World Bank (2006) to develop an *intervention framework* with typologies of innovation and other diagnostic tools for assessing the AIS of developing countries in order to identify and guide potential interventions.

Shortly after, the International Workshop on Enhancing Agricultural Innovation Systems (Rajalahti et al, 2008) was organized by the World Bank with ~80 participating experts representing donor agencies, development and related agencies, academia, and the World Bank. The workshop considered recent experiences with the implementations of the AIS framework, from which the paper presents recommendations for future strategies of AIS implementation: *(1)* AIS has no blueprint, but is an evolving framework and thus needs flexibility and learning. *(2)* AIS may be part of a government's national science and technology policy and strategy, therefore rural development agendas should also guide AIS strategies on innovation capacity. *(3)* Benefits and limitations of AIS must be communicated to stakeholders through the design and implementation process to provide economic arguments to both public and private sectors. *(4)* A consultation and discussion phase with multistakeholder platforms is needed throughout implementation in assessing and analyzing the existing AIS and identifying AIS-related needs. *(5)* It is necessary to map and analyze the status of the innovation system in order to fully understand the critical factors, actors, and conditions for innovation within the given context. *(6)* Finally, implementation strategies should systematically explore the innovation capacity and institutional issues of the system at the outset and develop a capacity-building plan.

The AIS framework has received wide application among large international organizations such as the World Bank (2012) and Food and Agriculture Organization of the United Nations (2014), and has been extended to encompass developed economies (Klerkx, 2012; Turner et al, 2016), whereas academic attention has mainly focused on evaluating the impacts of AIS interventions as well as adding additional insights (Mapila et al, 2012; Abebe et al, 2013; Schut et al, 2016).

2.1.2 Analytical Framework

The analytical framework comprises the IS structure of a specific country's agricultural sector, which defines key elements of actors and interactions in the system's domains of demand, education and research, enterprise, and intermediary actors, as well as supporting structures, and was developed as a key tool for conducting diagnostic assessments of the IS to be used for identifying suitable interventions for the system's innovation capacity. The main objective of the framework is to offer a description of the changing context, which reveals divergences between the innovation system and its practices, as well as a description of the changing demands imposed by changing contexts, which defines the opportunities and necessities for innovation, especially under rapid change. The framework thus provides four analytical tools, with can map out the linkages and interactions between the key actors throughout the domains, as well as the institutions and policies constituting the enabling environment for innovation:

(1) Key actors, their roles and activities in which they are involved: The composition of actors in the system may be very diverse, coming from the entire public and private spectrum of the economy which are linked with the development of innovations taking place within the sector. There may be a high diversity of actors coming from the entire public and private spectrum of the economy which are linked with the development of innovations taking place in the sector. Focusing on the diversity of public and private sector actors and appropriateness of their roles: *Who are the key actors associated with the case study, what roles do they play, and what are the strengths and weaknesses of these roles in promoting innovation?*

(2) Attitudes and practices of the main actors: These define the roles which actors can take, and may lead to weak or irrational interaction between actors or support good forms of interaction. They may also shape public and private interactions, promote interaction by multiple actors, and in general influence the success of innovation and especially poverty alleviating innovation. Attitudes and practices which define which roles organizations can take; lead to interaction for the wrong reason; lead to weak interaction among actors; support good forms of interaction; shape public and private sector interaction; promote interaction by multiple actors. Also, attitudes toward learning influence success and towards poverty influence pro-poor innovation. *What attitudes and practices are characteristic of the actors? How do the attitudes and practices promote or impede innovation?*

(3) Effects and characteristics of interaction patterns: These are general patterns of interaction, farmer-to-farmer interaction, company-to-company interaction, interactions of multiple actors such as interactions between businesses, the poor and the environment, and interaction involving technology transfer and public-private partnerships to improve research interaction. General patterns of interaction, farmer-to-farmer interaction, interactions of businesses with the poor and the environment, company-to-company interaction, technology transfer interaction, public-private partnerships to improve interaction with research, interactions of multiple actors. Focusing on formal and informal networks, links, and partnerships; the inclusion of the poor; the existence and functions of potential coordination and stakeholder bodies within the sector: *What interaction patterns exist in the sector? How do they strengthen the innovation capacity?*

(4) The enabling innovation environment (policies and infrastructure): The value chain approach is useful for identifying key actors in the production-to-consumption chain, as it combines market- and knowledge-based interactions needed for innovation to form a basis for forms of intervention which may help to encourage an effective innovation environment. Encouragement of value chain coordination appears to be an effective innovation environment. The value chain approach is a useful organizational principle for identifying the key actors in the production-to-consumption chain, combining market-based and knowledge-based interactions needed for innovation in the value chain to form a basis for forms of intervention. Focusing on: the role of policies of science, technology, and fiscal concerns; farmers and other organizations in defining research and innovation challenges; significance of legal frameworks: *How do science and technology, fiscal, and legal policies influence systemic innovation ability?*

2.1.3 Intervention Framework

The intervention framework is derived from the comparative case study analysis, and departs from earlier uses of the IS concept by providing additional guidance on diagnosis, as well as by adding specific ideas for potential interventions to develop the innovation capacity of the IS. The main aim of the intervention framework is to characterizes the sector's circumstances and stage of innovation by diagnosing the current and required capacity for facilitating innovation. The diagnostic features of the IS's development help to explain why certain features may be impeding innovation, and to identify promising arrangements, whereas the typology of the agricultural innovation environments helps the user rapidly assess the characteristics of the IS. On the basis of the diagnosis, the intervention framework then suggests principles and provides examples to guide the design of interventions that may help to strengthen innovation capacity. Thus, the framework has four elements, two pertaining to assessment and two to intervention:

(1) Typologies of innovation phases are based on the AIS' origins and phase of development, where the pivotal actors that initiate the innovation process are different, and may be either public or private actors, and thus the factors that trigger innovation may accordingly come from either policy or market interaction patterns. The initial conditions of the AIS tend to shape two distinct innovation trajectories; a publicly orchestrated or a private opportunity-driven system.

(2) Diagnostic features assessment can reveal divergences between the actors and practices, and changing demands imposed by the context, which is a unique contribution to the IS concept. These help explain why certain features may potentially be impeding the process of innovation, to which end promising arrangements of interventions can be identified and may be built upon.

(3) Principles of intervention were derived from examples in the case study analysis, and provides a set of principles to guide implementation of interventions for each typology phase. The AIS framework emphasizes the importance of the context-specific nature of processes which constitute innovation capacity, and thus the specific features of interventions need to match the development phase and the specific context of local institutional and policy settings.

(4) Intervention options were then finally developed for each specific development phase. Guided by the intervention principles, it was possible to identify potential interventions which are able to match the local context and provide pathways to strengthen innovation capacity.

2.1.4 Discussion and Limitations

The typologies of the analytical and intervention frameworks are not mutually exclusive, as actors often play multiple roles which may evolve over time. Yet, the typologies is still able to guide the identification of important actors and organizations in the AIS (World Bank, 2006). The AIS framework has been widely tested on developing and developed economies, and is widely adopted for assessing and designing interventions for agricultural innovation systems. The AIS framework is able to capture dynamic agricultural contexts of developing countries: (1) Niche sectors with strong growth patterns; (2) Sectors with strong global market integration; (3) Traditional sectors being transformed by growth in upstream activities in the value chain; (4) Lastly, the agricultural sectors is providing large employment opportunities for the poor. Similarly, as is covered in the next section of this chapter, the literature review of Brazil's AIS, as well as the more specific focuses on the innovation of ILS in Mato Grosso, show that ILS is a leading niche innovation in sustainable cattle farming, suggesting strong patterns of growth. The export rates from cattle production in the study region suggest a strongly integration of the agricultural system into the global markets. Cattle production has overall changed from smaller farms to large mechanized production systems, showing food chain industrialization. Finally, the cattle production sector still provides employment opportunities for the poor in the region. Thus, the AIS framework provides a good fit for a case study of ILS innovation in Mato Grosso. Since AIS framework concerns the factors which affect the demand for and use of knowledge, it is useful as a framework for investigating demand for and use of knowledge for ILS innovation in Mato Grosso, and is particularly suited for a focus on the perspective of farmers, as they represent the final demand in the innovation and adoption of ILS innovation.

2.2 Literature Review

Over the last thirty years academic literature concerned with sustainable agriculture in Brazil has investigated different aspects of Integrated Agricultural Systems, of which ILS is a subset, while the AIS concept is a relatively new addition to the literature on agricultural innovation. As the AIS framework forms the theoretical basis for this thesis to investigate ILS innovation, this section first reviews the literature of applications of the framework in the Brazil, whereafter it reviews the literature on the different aspects of ILS innovation taking place in Mato Grosso.

2.2.1 The Brazilian AIS

The study by the Organization for Economic Co-operation and Development (2015) finds that broad economic reforms in the 1980s and 90s strongly promoted agricultural development, resulting in a remarkably growth of Brazil's agricultural sector over the past two decades. Driven primarily by external demand, the growth was enabled by productivity developments and structural adjustment, agricultural technology research, and vast unexploited resources. Sustained agricultural growth has thus become economically critical to the nation, as well as on an international level due to Brazil's role as a leading international supplier of food products, and is socially important as it contributes income opportunities and affordable food for the poor.

Yet, the past key drivers of growth have weakened, demanding increased cost-competitiveness. Brazil faces the challenge of reconciling its agricultural growth with its societal objectives. The structural deficiencies characteristic of an emerging economy are a challenge to overcome. The conditions for innovation are a significant constraint on agricultural growth potential. Businesses face restrictive and complex regulations, resulting in high costs of doing business. Businesses bear a substantial tax burden and regulations incur high costs to comply with taxes. Long-term domestic credit for innovation is scarce, and access to the available credit is costly. Commitments to accelerate the development of infrastructure and education must be sustained. Agricultural policy could be more strongly oriented toward productivity and sustainability.

Overall, the AIS lacks capacity to adopt innovation, to which the paper recommends policies: (1) Improve overall business conditions by easing regulatory burdens such as tariff protection, and moving towards a more simple single national indirect tax system, as well as leveling the playing field for state and private lenders to facilitate development of private long-term finance. (2) Enhance the economy's development capacity by accelerating infrastructural development, modernizing labor regulations and labor market programmes, and broadening education access, as well as improving agricultural vocational training system, and industry-school cooperation. (3) Strengthen agricultural innovation incentives by halting distortive support to producers via downsizing concessional loans for working capital to commercial producers, increasing credit support to technological innovation, advanced farm management, and environmental practices. (4) Strengthen direct incentives for innovation by increasing the capacity and flexibility of public R&D agencies to collaborate with other R&D providers both domestically and abroad. Policies should strengthen links between R&D and technical assistance by promoting cooperation of research across sectors and awareness-raising networking, and supporting technical assistance, training opportunities and rural extension services for small family farms.

The few academic studies using the AIS framework have been able to replicate these findings and contribute to the literature by providing additional specific insights into the Brazilian AIS: Moreddu et al (2017) replicate the previous findings, and contribute to the literature by concluding that the strengthening of public research institutions have indeed created a large R&D capacity and innovations with high adoption rates by large farms, and resulted in high productivity and growth, yet overall the system still has many challenges. Filho et al (2018) similarly replicate the previous findings, and find the AIS's main challenge lies in increasing adoption rates of smaller farmers, and adds to the literature by concluding that the diversity of small farmers requires specific policy actions to promote production and allocate resources to the outreach and education of rural extension services in the diverse regions of the country.

While the AIS framework has seen wide usage, only a few application have focused on Brazil, however the studies provide crucial historical context to the AIS' development and challenges. Such applications of the AIS framework provide a useful context of the Brazilian AIS, however, since the AIS framework is mostly applied to examine the entire AIS of a country, the previous literature has little information on the specifics of how the system interacts with ILS innovation, nor on the specific agricultural context of the study area of Mato Grosso.

2.2.2 ILS in Mato Grosso

This section covers the main research on the topic of ILS and its innovation in the study area. There is a substantial body of literature focused on a large variety of actors and interactions in the Brazilian AIS involved in the innovation of ILS in the study region of Mato Grosso. However, most studies focus on specific issues relating to the innovation of ILS rather than a holistic approach such as the AIS framework to study ILS, which may be necessary to detect interactions between the diverse systemic variables (de Moraes et al, 2014; Garrett et al, 2017b). The literature review is informed by the themes of the AIS domains in the analytical framework: Demand, research and education, intermediary, enterprise, as well as support structures. Overall, four essential questions to ensure a holistic review of the literature covers all domains:

(1) Key actors, their roles and activities in which they are involved: Who are the key actors associated with the case study, what roles do they play, and what are the strengths and weaknesses of these roles in promoting innovation?

(2) Attitudes and practices of the main actors: What attitudes and practices are characteristic of the actors? How do the attitudes and practices promote or impede innovation?

(3) Effects and characteristics of interaction patterns: What interaction patterns exist in the sector? How do they strengthen the innovation capacity?

(4) The enabling innovation environment (policies and infrastructure): How do science and technology, fiscal, and legal policies influence systemic innovation ability?

Demand domain

Consumers of food and food products in rural and urban areas; Consumers of industrial raw materials; international commodity markets; policy-making process and agencies.

Unclear rules on land tenures cause many land speculators occupy, deforest and sell undesignated lands illegally or via legal loopholes, and flood the market with low-cost land. This creates less incentive for adopting ILS, and the confusion and lack of enforcement in the recent changes to laws on land occupation have encouraged this dynamic Stabile et al (2020). Slaughterhouse companies have implemented responsible sourcing policies and risk management mechanisms in response to international demand (Strassburg et al, 2012). However, such governance efforts often ignore production practices, and adoption of certifications is very limited, which limits the effect on ILS adoption (Garrett et al, 2017a). Commitments to ILS products could be accompanied by direct support to producers and supply chains to increase productivity while complying with legislations (Stabile et al, 2020). End consumers and retailers in cattle supply chains play increasingly large roles in determining rules and incentives regarding production processes. Access to niche markets that value sustainable cattle production may be especially important for ILS adoption. Consumers in Europe have shown interest in products not associated with deforestation (Garrett et al, 2017a). The Federal government interacts with ILS primarily via the Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA) by means of participating in program and policy design, as well as by mobilizing funds for the ABC plan. On the state level, the Mato Grosso state government

agency the Secretary of State for the Environment (SEMA) interacts with ILS by means of program and policy design on the environment and REDD+. Other agencies, such as Secretaria de Estado de Desenvolvimento Rural e Agricultura familiar (SEDRAF) participate in program and policy design, while Empresa Mato Grossense de Pesquisa Assistencia e Extensao Rural (EMPAER) work on strengthening extension services, and Instituto de Defesa Agropecuária de Mato Grosso (INDEA) mainly participates in monitoring of ILS programs. The municipal government participates in ILS projects for ranchers (Strassburg et al, 2012).

Research and education domain

National and international agricultural research organizations; universities, technical collages, and private research foundations; private companies and NGOs.

The Innovation of ILS depends on the generation of knowledge to create basic concepts that can be used to develop practical technologies to be applied by farmers (de Moraes et al, 2014). Most of the technologies and knowledge necessary to implement various ILS systems have been developed by Embrapa and companies, universities and state research institutions (Embrapa, 2021). Embrapa is a semi-autonomous state-owned research corporation affiliated with Brazilian Ministry of Agriculture, which since its inception on 1973 has worked on developing technologies, knowledge and technical-scientific information for at Brazilian agriculture, including ILS (Caviglia-Harris, 2018). The adoption of ILS has been supported by industry and promoted by Empraba in the form of 'Best Ranching Practices,' which includes extension visits, research efforts and programs to improve access to credit (Caviglia-Harris, 2018). In the late 2000s Embrapa created a new research portfolio on ILS, and established a new research unit focused on ILS in Mato Grosso to function as a hub for research on low carbon agriculture technologies and system integration, housing researchers from other Embrapa centers to enable knowledge-sharing between them (Garrett et al, 2017a; Embrapa, 2021).

A 2012 project by Embrapa investigated the use of ILS as a local development for Mato Grosso, considering economic, social, and environmental impacts, and the alignment of this strategy to Federal Government programs, which contributed to public promotion of ILS (Embrapa, 2015). The limited number of researchers based in the region creates a lack of capacity and effectiveness in providing adequate and equitable knowledge access for small farmers, which limits guidelines development and promotion of ILS (Garrett et al, 2017a; West et al, 2021). Research, education, and extension institutions in the region, including Embrapa, public and private schools and universities, have concerned mainly on research and outreach activities focused on increasing yields and profits in traditional ILS practices (Garrett et al, 2017a). ILS projects by Embrapa are still recent, and will take several years before emerging knowledge about ILS can be validated and consolidate. (Garrett et al, 2017a) While the diversity of ILS allows for wide usage by farmers in different agro-climatic contexts, its diversity makes it hard for policy makers and scientists to define an ideal integrated system, especially on maximum profitability and optimal scale of implementation (Garrett et al, 2017a). Universities across Brazil, but especially local universities in Mato Grosso, participate in capacity building, development and implementation of ILS programs (Strassburg et al, 2012). As an example, a local university, UNEMAT Alta Floresta, Mato Grosso, was involved in the Novo Campo pilot program to support knowledge flow to farm staff by training agricultural extension officers in ILS trough environmental licensing, farm financial analysis, and use of farm management

software. (Zu Ermgassen et al, 2018) Most on-farm ILS experiments in Mato Grosso were carried out by forestry companies and livestock production farms residing in degraded pasture areas (Embrapa, 2021). Yet, the research on ILS research on is not aligned with the systems farmers tend to adopt. Experimental ILS plots are designed to minimize units variation and maximize replications. However, farmer experimentations do not resemble the ideal ILS that researchers are studying, but is a more realistic look at the types of ILS farmers are willing to adopt (Garrett et al, 2017a).

Intermediary domain

Extension services and donors; NGOs and consultants; farmer / trade associations; private companies / entrepreneurs.

Technical assistance service providers from the private sector work as recipient and multiplier of capacity-building actions to assist farmers on cattle ranching productivity improvement, including ILS, and environmental compliance (Strassburg et al, 2012). From the public sector, extension services such the Agency for Technical Assistance and Rural Extension (ANATER) work to advance ILS by strengthening the system's capacity to cover more farmers and issues, as well as facilitate access by poor farmers, with the aim of increasing the productivity and environmental sustainability of farms and to link them to markets (Caviglia-Harris, 2018). ANATER ensures the efficient and effective use of public sector investments in ILS technology transfer to local farmers by leveraging resources from the private sector (de Moraes et al, 2014). The National Program for Access to Technical Education and Employment (PRONATEC) also works to improve extension quality and professional education for farmers (Garrett et al, 2017). However, the current technical assistance provided by government agencies is not modernized and is not adapted to the new sustainable production models in ILS (Stabile et al, 2020). Limitations in rural extension and technical assistance are important barriers to adoption of ILS. There is a need for training and qualification of professionals to ensure that projects are economically, socially, environmentally sustainable, and culturally accepted (de Moraes et al, 2014; Garrett et al, 2017a). Several farmer organizations such as Famarto, Aprosoja, CNA and Acrimat have participated in design and coordination of programs and policy for ILS, as well as in mobilize farmers to engage in the programs. Other farmer organizations, such as IMEA provide expertise on sector economics and monitor program implementation, while SENAR participate in the implementation of capacity-building actions. On the smaller scale, local farmer unions participated in pilot projects and worked to mobilize farmers to engage in the ILS programs (Strassburg et al, 2012). International Institute for Sustainability (Instituto Centro de Vida (ICV) is involved in training agricultural extension officers in ILS through environmental licensing, farm financial analysis, and farm management software. ICV also collaborates with Embrapa and local universities (Zu Ermgassen et al, 2018; Guerra et al, 2014). In the private sector, numerous environmental NGOs have been involved in program and policy design, especially focusing on managing pilot programmes for cattle ranchers, as well as mobilizing grants for design and implementation of pilot programs. International cooperation among foundations funded ILS program design and implementation (Strassburg et al, 2012).

The intermediary domain is dominated by NGOs, experts and other stakeholders as key actors which fulfill the roles of supporting the enterprise domain in ILS adopting and innovation. Both public and private commercialization cooperatives and agencies were present in the sector.

Private farming consultants had an active role in supporting innovation in the enterprise domain, targeting farmers, farmer cooperatives/communities, integration of the poor, and municipal engagement management. Yet, these were not ubiquitous, often lacking capacity building. Private professional unions and farmer cooperatives were also present in supporting interactions with enterprise and support structures. Private professional unions worked to increase networks between adopters and non-adopters, promoting technical meetings, training sessions and opportunities for technical support, as well as the implementation demonstration units on farms for show-cases targeting other farmers. Certification schemes were also developed by the professional networks, delivering financial rewards to help ILS producers meet market prices. ILS farmers were generally members of professional associations or unions, and thus more exposure to innovations via contact with innovative peers, which was a main innovation driver. Public municipal unions were also present to support ILS farmers, but with limited success, since extension agents often visiting farms with the purpose of checking for compliance with environmental laws or tax payments, rather than directly supporting farmers in practicing ILS.

Multilateral linkages between intermediary NGOs, local municipalities and local universities also existed in a few areas, which focused on supporting knowledge flow to farm staff, training additional agricultural extension officers, environmental licensing, and farm financial analysis. Embrapa experiments and demonstration plots, with agricultural extension officers working with farmers to introduce ILS practices. Proximity to Embrapa ILS experiments drove better educated households are more open to innovations. These public investments in extension services yielded substantial results of ILS expansion and innovation, but access remains limited. Private education programs exhibited by farmers provide via public experiments and demonstration plots with open-farm field days where local farmers can witness and learn about new management options, rural credit access, ecosystem services and environmental practices, which helps to overcome risk aversion by directly seeing the benefits of ILS systems in action. Innovative knowledge spreads mostly via word-of-mouth between farmers, and to this end especially private education initiatives have successfully promoted the existence of local champions, long-term commitment of key players, and strategic partnerships among local stakeholders. Awareness can thus be raised effectively with on-farm demonstration units, but these have so far not been common. Public environmental policies blacklists farmers with bad environmental practices, while Embrapa certificates is awarded to ILS farmers, which encourages ILS adoption indirectly (Guerra et al, 2014; Gil et al, 2015; Gil et al, 2016; Latawieca et al, 2017; Zu Ermgassen et al, 2018; Cortner et al, 2019).

Enterprise domain

Farmers; companies and industries related to agriculture, particularly agroprocessing; Transporters, commodity traders, and input supply agents.

Historically, small family farming have not modernized along the rest of Brazil's agriculture, stemming from low income, lacking basic infrastructure and institutional support, and poor access to technical assistance, farming technology, and markets. Lacking technical assistance, know-how, or resources to implement ILS and invest in inputs results in low productivity, which generates insufficient income and encourages more deforestation to increase production Stabile et al (2020). The actions of farmers generally responds directly to political incentives and discourses. Promotion of sustainable development such as ILS rely on effective funding

mechanisms, which are still sparse in the area West et al (2021). Cattle production has shifted from small farms to large mechanized cattle production systems. The high deforestation rates and low stocking rates of cattle ranching, and low adoption of ILS, are likely due to low labor requirements and the availability of cheap land Stabile et al (2020). While both ILS farmers and ranchers require for inputs for their production, there are high upfront costs of inputs required for implementing ILS (Strassburg et al, 2012). There is a long historical culture of generations of improving and mastering specific systems, developing social capital for sharing information and reaching cooperative arrangements for purchasing inputs and selling outputs. (Garrett et al, 2017a) These factors create strong incentives for farmers to maintain the same practices, at least until they see their neighbors transitioning to new systems. In theory, farmers are incentivized to adopt ILS in order to abide by reforestation demands and maintenance of land ownership, as well as obtain higher production diversity (Embrapa, 2021). Large farms that divide their area into crops and livestock can still achieve economies of scale, while small farms can take advantage of higher labor requirements of ILS. For medium sized farms the advantages of integrated systems are less clear. Immigration backgrounds often play an important role in farmer's decision-making (Garrett et al, 2017a). Better targeting of research, extension, and financing for ILS requires efforts to focus in regions where farmers will have the greatest incentive and ability to adopt ILS (Garrett et al, 2017a). The adoption of ILS depends on the availability of information regarding the agronomical and economical potential, the market demands and the existence of governmental policies for sustainable development (de Moraes et al, 2014). The new federal government's plans, actions, and anti-conservation discourse are accelerating deforestation, which may reduce incentives top adopt ILS West et al (2021). The employment of more diverse policy tools beyond credit subsidies to encourage adoption of sustainable intensification strategies, including: education programs, payments for the ecosystem services, improved transportation and supply chain infrastructure to support intensification and help create a climate of innovation. In response to international markets which are demanding deforestation-free beef products, many producers and companies, especially meatpackers, have excluded products associated with deforestation from their cattle production supply chains, such as non-ILS products Garrett et al, 2017a; Stabile et al, 2020). The profitability and productivity of ILS is dependent on the presence of supporting business such as input suppliers, storage facilities, traders, and processers (de Moraes et al, 2014). The quality of transportation networks and the availability of qualified labor is highly linked to the development of the supply chain. Much of this supply chain infrastructure is still evolving. Processing units for soy and cattle are not always close to each other, which poses an obstacle to the implementation of ILS. Farmers have created cooperatives to solve minor infrastructure deficiencies. However, deficiencies in the interstate road networks and waterways, as well as international port infrastructure pose serious problems for the competitiveness of agricultural production. Private investments in infrastructure contributed to lower transportation costs. A frequently mentioned barrier to ILS adoption is the difficulty in finding qualified labor and high labor prices. High labor costs and low labor availability create strong incentives for farmers to specialize in traditional cattle ranching and increase mechanization to increase labor productivity. This negatively impacts incentives to invest in ILS. In public policy, the limitations remaining in rural extension and technical assistance are key barriers to the adoption of ILS. Thus, there is also an urgent need for training and qualification of professionals with a systemic view to ensure that the projects in this field are economically viable, and environmentally sustainable, (de Moraes et al, 2014)

Non-ILS farmers were generally aware of ILS and understood its proposed benefits. However, there was a overall cultural preference of risk aversion toward new technologies among farmers, especially financial concerns of the high up-front cost, causing many to forego the practice. Farmers involved in ILS innovation had a more favorable attitude towards change, and seemed better able to cope with the risks involved in the implementation of a new agricultural practice. Culture was a larger barrier in the amazon biome of Mato Grosso, with risk-averse attitudes towards ILS was the dominant cause for non-adoption. Here, adopters felt that the benefits of better farm management and increased productivity, increased yields, and thus income outweighed the high up-front costs. Generally, environmental concerns were not significant. Adopting and non-adopting private farmers sook profit and security for their cattle production. To this end farmers involved in ILS saw it as a way of diversifying and securing their profits. However, most ILS farmers saw ILS more as a complementary strategy rather than as a business option to completely replace their ranching, and preferred to implement only on owned land. The risk-averse culture had a negative feedback loops often creating slows innovation inertia. Regular labor was requirements for ILS were low, since ILS was applied at a large-scale farms using mechanized production. However, availability of skilled labor and other sources of know-how was important, yet lacking, which thus constituted an innovation barrier. Since IS adopters usually implemented on privately owned lands, by individual farmers, with not much cooperative interaction between farmers. Interactions with investment groups from the Support Structures domain opting for low-risk traditional systems with immediate profit. Farmer cooperatives were present, innovating through participation in social networks, such as professional associations. This was characteristic of ILS farmers, but mainly earlier adopters.

The transition from low-input, low-risk extensive systems to resource intensive ILS practices have a high up-front cost, both financial and other resources, such as available labor, machines and favorable farm layout. Due to their high investment costs, farm size and resources, especially financial resources, were needed for most ILS farmers, and thus larger farms adopted. ILS adopters have less land rental contracts, and implemented ILS mainly on land they owned. ILS farmers were slightly more educated, which possibly allowed them to better assess benefits. In general farmers involved in ILS had somewhat larger farms, more diversified income, higher education and larger networks, older age, and more availability of financial and human capital. The majority of farmers involved in ILS only applied the practice only on part of their farms. ILS practices were not always profitable, especially not for very large farms, who had had little incentive to adopt, nor for average municipalities, where smaller farms did not have the capacities to participate in ILS practices, which left many farmers unwilling or with many barriers to get involved in the innovation of ILS. The exception to this was poorer municipalities where small land owners were the main adopters, due to reduced risks associated with ILS. Cattle ranchers that adopted ILS perceived ILS as a beneficial strategy for increasing the economic value and competitiveness, and as a necessity to maintain their livelihood amidst declining profits and increased environmental oversight. Both adopters and non-adopters described numerous structural barriers that impeded adoption of ILS in the region, including: problems obtaining qualified labor, a lack of marketing options, poor infrastructure, and an unsupportive regulatory environment. Cultural motives drove decisions regardless of expected profit-maximization *(Guerra et al, 2014; Gil et al, 2015; Gil et al, 2016; Latawieca et al, 2017; Zu Ermgassen et al, 2018; Cortner et al, 2019).*

Infrastructure and support structures

Banking and financial system; transport and marketing infrastructure; professional networks, including trade and farmer associations; education system; agricultural and environmental policies.

The Brazilian AIS involved in ILS is highly diversified, with a wide range of actors in the public, private and nongovernmental sectors, all serving different roles at different scales, with collaboration of stakeholders from across the entire cattle supply chain (Garrett et al, 2017a). The support structures are mainly infrastructure and rural credit systems were dominated by actors from the public sector, with smaller actors from the private and multilateral present. A variety of credit systems for farmers were present in the system to support their activities. There was generally enough credit available, but mainly ILS producers used credit on a regular basis, while cattle ranchers relied mainly on their own capital for farm expenses. From the public sector, there where credit programmes stimulate the development of family farming in order to target the issues of lacking labor and knowledge, which supported the qualified labor concerns of ILS farmers. ABC credit provided financial support for both ILS farmers and cattle ranchers, with the focus on supporting adoption of large-scale ranchers. Especially smallholders were not targeted by the ABC credit, despite their lack of participation in ILS. ABC credit had had little impact on ILS innovation due to poor geographic scope, lack of awareness from farmers, bureaucracy, unpreparedness of bank agents responsible for issuing the credit, and was often outcompeted by other credits options, such as other public rural credits providing basic financial support for farmers. ABC adoption by farmers was low despite the all the incentives. Major international funding programmes in collaboration with stakeholders across the supply chain were present in the system, working with more sustainable agriculture development including financial support for ILS farmers, but encountered similar problems of allocation. From the private sector, bank loan eligibility was similar for ILS farmers and cattle ranchers, however ILS farmers utilized this credit option much more than ranchers, showing the capitalization level of ILS farmers, which explains their lower risk aversion towards adoption. (Guerra et al, 2014; Gil et al, 2015; Gil et al, 2016; Latawieca et al, 2017; Zu Ermgassen et al, 2018; Cortner et al, 2019)

Brazil's Low Carbon Agriculture (ABC) Plan was launched and coordinated by MAPA in 2010, and set targets to reduce agriculture GHG emissions in countrywide by 2020 through loans with low interest rates and extended term for investments in activities such as ILS projects (Strassburg et al, 2012). The ABC plan meant as a key instrument in increasing ILS adoption. Mato Grosso has received the most of ABC credit among States in the Legal Amazon, accounting for 44,58% of the total credit released in the region until 2016. However, The amount of ABC credit used specifically for ILS is much lower than for other green agriculture, even as it has increased in recent years. By 2017 less than 10% of ILS farmers in Mato Grosso had obtained ABC credit, and most these farms were medium to large in size. In Mato Grosso, ILS adoption is not higher in counties where ABC disbursements are higher. Consequently, it appears that current growth in ILS usage is only partially linked to the incentives provided by the ABC program. (Garrett et al, 2017a) The capacity of bank agents to issue ABC loans is hampered by insufficient information about rules and farm eligibility, as well as relatively high interest rates on loans. (Garrett et al, 2017a). Additionally, the share of agricultural credit for sustainable agriculture proposed by the ABC credit represents only 2 % of total rural lending

Stabile et al (2020). Other lines of credit are available, such as the Bolsa Verde program, which integrates environmental objectives into programs designed to combat poverty, and pays poor households for forest conservation as measured at an aggregate community level. This helps increase the adoption of ILS among farmers who are the least likely to adopt ILS (West et al, 2020).In the private sector, banks that implement credit programs for ILS such as the ABC program adapt financing rules to the conditions of the ranchers sector in order to provide capacity-building for farm-level ILS project development (Strassburg et al, 2012). However, the public and private sector incentives to adopt ILS on private properties is limited. For example, many public agriculture investments go through other subsidized credit programs which do not directly support efforts such as ILS implementation Stabile et al (2020). Farmers have a positive perception of the interest rates and grace period of ABC loans, but view the environmental and bureaucratic requirements for such loans as prohibitive. (Garrett et al, 2017a)

The level of local supply chain infrastructure such as transportation networks, storage facilities and input retailers is a crucial limitation of agricultural development (Guerra et al, 2014; Gil et al, 2015; Gil et al, 2016; Latawieca et al, 2017; Zu Ermgassen et al, 2018; Cortner et al, 2019). Primary production costs in Mato Grosso are the lowest in Brazil, however the logistics costs in Mato Grosso are very high given the long distances that trucks must travel along poor roads. There is generally insufficient investment in infrastructure which affects productivity gains, export performance and domestic market integration opportunities (Arias et al, 2017). ILS adoption in Mato Grosso is higher in regions nearby slaughterhouse infrastructure, and mainly involves cattle ranchers introducing cropping into their systems. Due to the high yield and market prices for soy in the Legal Amazon and existing infrastructure, farmers have the greatest incentive to adopt ILS in areas with low productivity cattle ranching, but with nearby grain supply chain infrastructure (Garrett et al, 2017a).

In the 1970s and 80s the government began promoting modernization of the agricultural sector and individual cash crops, and many farmers in Brazil abandoned ILS (Garrett et al, 2017a). Between 1995 and 1998 through programs administered by the federal government encouraged poor farmers to farm unclaimed forest land, after which they could keep the land. Thus, the availability of low-cost land reduced incentives for farmers to adopt ILS practices (Sills et al, 2014; Caviglia-Harris, 2018). However, following the 1990s the usage of ILS began increased again following increased public and private efforts (Garrett et al, 2017a).The Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm) launched by the government in 2004, as well as Brazil's National Plan for Climate Change (NPCC), worked to reduce the land area of cattle ranching by protecting forested areas, and included ILS is a key part of its strategies. The policies was responsible for a significant reduction of deforestation in the region via actions such as better satellite-based monitoring, blacklisting of municipalities, expansion of protected areas, land tenure regularization, restrictions to credit access, and different legal moratoria. Such policies, as well as taxes on traditional pasture-raised cattle or subsidies for ILS-raised cattle may lead ranchers with large yield gaps to invest in ILS. Yet, effective implementation has been lacking due to the slow bureaucratic processes, while implementation agencies are often lacking logistics, resources, and institutional capacities (Caviglia-Harris, 2018).

Since 2007 the Bolsa Floresta program (Forest Alliance program) aimed to improve the livelihood opportunities of rural farmers through a financial compensation program to pay a small economic incentives to households for their commitment to zero net deforestation, as well as implementation of integrated conservation and development components (Sills et al, 2014). In 2010 Brazil committed to reducing Amazon deforestation for the United Nations Framework Convention on Climate Change, which including actions such as the expansion of ILS practices (Embassy of the Federative Republic of Brazil, 2010). As an extension of such efforts the international collaboration on the Nationally Appropriate Mitigation Action (NAMA) plan works to further advance the adaptation in ILS and other such systems (Caviglia-Harris, 2018). In 2010 Reducing Emissions from Deforestation and Forest Degradation (REDD+) policy development in Mato Grosso was led by the SEMA as a technical, open working group in the Mato Grosso State Forum on Climate Change. The working group shared REDD+ experience with other Brazilian states and abroad, and worked on developing a state REDD+ draft law, which went through a wide adaptive public consultation process. The framework for REDD+ established state-level emissions reference levels and registries, monitoring systems, and security reserves, as well as a state fund for REDD actions and a public-private mechanism for project financing, especially prioritizing ILS for small farms (Strassburg et al, 2012). However, there have been lacking mechanisms for payments for environmental services (PES) to compensate farmers for lost profits associated with conserving forests on their land, which could be reinvested in ILS to improve productivity. The government does not currently promote private or public compensation programs using PES or REDD+ mechanisms, however, the government has recently approved legislation to regulate such mechanisms Stabile et al (2020).

In 2013, the National Integrated Crop-Livestock-Forestry Policy by the government aimed involving local communities, and encouraging the adoption of certification from ILS with the aim of reclaiming degraded areas, increasing yields, food quality, and farmer income. (Garrett et al, 2017a; Empraba, n.d.) There is of yet little research on the impacts of this policy the area. Poorly defined land tenure rights and limit access to credit reduce the incentive to adopt ILS. Lacking insurance against weather and extreme climatic and economic events also reduces farmers' incentives to make investments in ILS, given their often long payback periods (Garrett et al, 2017a). The lack of environmental criteria for most public credit, and the high implementation costs of ILS may discourage farmers from adopting systems such as ILS on their property to help them meet commercial demands for deforestation-free products, comply with environmental legislation, and increase the long-term sustainability of production Stabile et al (2020). The Brazilian Forest Code sets a required amount land on private properties to remain forested, and restricts clearing. The Forest Code has existed in more than 80 years, but has been largely ineffective in reducing deforestation due to lacking adherence and enforcement. However, through the 2000s enforcement has begun increasing (Garrett et al, 2017a; Santiago et al, 2018). The PPCDAm saw the government apply real time monitoring of deforestation, and direct more support to stopping illegal deforestation, and enact credit restrictions for priority municipalities and individual farmers in the Amazon biome implicated with high rates of illegal deforestation. A 2012 revision to the Forest Code required farmers to register their properties with State environmental agencies in the geo-referenced database Rural Environmental Registry (CAR), and develop a plan to comply with the forest code in order to access government banks credit. The 2012 revision also established possibilities to implement tax incentives along the supply chain for products from farms with certified environmental

compliance (Garrett et al, 2017a). The pending mechanism of Environmental Reserve Quotas (CRA) proposed in the 2012 Forest Code revision would establish a system for trading forests certificates, which makes it possible for landowners with excess forested areas to transfer their deforestation rights to offset deficits of illegally deforested land elsewhere that needs to be restored (Santiago et al, 2018). Theoretically, this would reduce demand for illegal deforestation, enabling more farmers to comply with the forest code and be able to access credits to implement ILS Stabile et al 2020). Challenges of enforcing and maintaining effective policies are significant, and the powerful cattle industry lobby played a key role in reducing the amount of land protected by the 2012 revision to the Forest Code Caviglia-Harris, 2018). Yet, complying with the Forest Code also does not yield any useful certification. This is expensive and did not help with the farmers with ILS implementation, as even where farmers could access credit, no credit lines supported costs of compliance with the Forest Code. Additional barriers of a lack of marketing options, as market prices received for cattle are the same for ILS and non-ILS produced goods, but average productivity of cattle ILS adopters was about three times higher. Farmers receive same price for product, regardless of environmental management. There were no public certificates, but private ones did exist, but had limited broader recognition (Guerra et al, 2014; Gil et al, 2015; Gil et al, 2016; Latawieca et al, 2017; Zu Ermgassen et al, 2018; Cortner et al, 2019). Recent changes to the Forest Code, such as the indefinite deadline extension for the Environmental Rural Registry and the possible regularization of public lands illegally grabbed will likely increase deforestation and delay liabilities regularization and restoration policies (Silva Junior et al, 2020). The environmental policies currently being proposed by the federal government threaten to dismantle Brazil's Forest Code and may have already contributed to the recent surge in land speculation and deforestation in the area, which may reduce ILS incentives Stabile et al (2020). A recent extension to the Terra Legal government program, which gives long-time occupants of undesignated forests a pathway to legalize their land, encourages more land grabbing by land speculators, and thus discourages the adoption of ILS for existing pastures Stabile et al (2020). The Mato Grosso state government has been proactive in setting targets to increase beef production while promoting forest conservation and social inclusion. However, while MAPA is working to increase beef production by ~43 % by 2030, the strategy to achieve the targets follows the old paradigm of expansion through deforestation, rather than by expanding ILS, which clashes with the goals of the federal Nationally Determined Contribution to restore forests and end illegal deforestation in the Amazon by 2030 Stabile et al (2020). The environmental issues in policy changes by Brazil's president Jair Bolsonaro and large landholders and their representatives on cattle ranching practices, may hinder ILS innovation. These policy changes include measures which are weakening the country's environmental agencies and forest code, granting amnesty to deforestation, approving harmful agrochemicals, reducing protected areas, and denying the existence of anthropogenic climate change. International imports of Brazilian beef are stimulating these impacts. (Ferrante et al, 2019; Azevedo-Ramos et al, 2020) Despite the lack of coherence in federal policies, ILS are being tested by producers with next to no public incentives, yet new incentives and strategic investments could accelerate its widespread adoption (Stabile et al, 2020). Available financing options, management, and training of local farmers are of key importance to the diffusion of ILS among smallholders (Blinn et al, 2013; Futemma et al, 2020). Most adopters of integrated systems implement only the crop and livestock components, and omit forestry (Strassburg et al, 2014; Wilson et al 2016; Arias et al 2017).

2.2.3 Research Contribution

Since most research into the innovation of ILS has focused on examining the different barriers to innovation from diverse perspectives of the specific actors in the AIS, there is a gap in the knowledgebase of how to design comprehensive interventions to overcome the diverse barriers. Also, in previous studies which provide a general application of the AIS framework on Brazil, the lack of focus on the specifics of how the AIS interacts with ILS innovation and the context of Mato Grosso may limit the impact of findings and proposed interventions for ILS innovation. Considering the critical state of deforestation linked to cattle ranching in the Brazilian Amazon, especially in Mato Grosso, there is a need for research which in particular applies the AIS framework to consider the specifics of how the Mato Grosso AIS interacts with ILS innovation. Thus, this thesis contributes to the extant literature by investigating the prospects and obstacles of ILS innovation in Mato Grosso specifically as interactions occur in the study region through the contextualization of the AIS framework, and can thus propose comprehensive interventions.

3 Data

3.1 Source Material

In order to examine the prospects and obstacles of the innovation of ILS in Mato Grosso, Brazil, this thesis mainly relies on secondary data on ILS innovation derived from the literature review. The AIS framework is designed to source its information from available empirical material, such as earlier studies exploring science, technology, and innovation policy issues in the sector, as well as interviews with key informants and sector specialists in the area (World Bank, 2006). As such, secondary data on each domain of the AIS analytical framework is covered in the literature review with empirical data from academic research, and reports from different actors. The literature review includes a set of case studies concerning ILS initiatives in Mato Grosso, and provide the perspectives of farmers in enterprise domain and intermediary domain, including their perspectives on their interactions the enterprise, intermediary, and other domains (Guerra et al, 2014; Gil et al, 2015; Gil et al, 2016; Latawieca et al, 2017; Zu Ermgassen et al, 2018; Cortner et al, 2019). The data from the different case studies is aggregated to present an overall perspective of farmers in the study region. An in-depth process on the aggregation, including the data sample and collection methods of each case study are shown in Appendix A.

3.2 Data Evaluation

This thesis uses qualitative data following the guidelines of Creswell (2007) in the form of qualitative documents, which under a qualitative research design enables the gathering of detailed insights into the workings of social phenomenon involving many different actors embedded in a particular social context, which is beneficial to the aims of this analysis. Considering the availability of published case studies and broader information on Brazil's AIS, the use of qualitative documents is sufficient to facilitate encompassing qualitative research. Additionally, building the analysis on qualitative documents allows for insights into detailed values of participants, and enables a useful non-obtrusive data collection during COVID-19. The diverse perspectives of ILS innovation across AIS domains ensures a holistic data sample, and the secondary data's reliance on empirical data from peer-reviewed academic material, reports and accessible databases and websites ensures reliability, representativity and validity. Given the broad sampling of empirical literature covering different aspects and perspectives, the data is representative of ILS actors in Mato Grosso at different socio-geographic levels. Regarding the context of recent political changes in Brazil's AIS, considering the recency of Jair Bolsonaro's government taking office in 2019, the availability of detailed data is sparse, but should be enough to provide the necessary context for an up-to-date analysis of the AIS. While the historic context of the ILS interactions is generally covered by the literature review,

the perspective of farmers from the case studies is limited to events in between 2011 and 2018. An overview of the different characteristics of the set of case studies applied in this research are presented in Table 1, which may be used to identify common and differing perspectives, which is important to determine the aggregated generalizability of the data for the analysis. Details on the reliability, representativity and validity of the case studies is in Appendix A.

Table 1. Comparison of case study characteristics. Author's own creation based case study data. Direct evidence is shown in plain text, while estimates are shown in brackets.

Case	**1**	**2**	**3**	**4**	**5**	**6**
Geography	Mato Grosso (Cotriguaçu municipality)	Mato Grosso (Overall)	Mato Grosso (Overall)	Mato Grosso (Amazon biome)	Mato Grosso (Overall)	Mato Grosso (Overall)
Time	2011	2012-2013	2012-2013	2013-2015	(2004-) 2012-2015	2014-2018
Sample	122 farms	134 farms	143 farms	250 farms, 25 focus group, 17 experts	13 farms in Mato Grosso, 40 (6500) in Amazon states	9 farms in Mato Grosso, 33 farms in Amazon, 31 experts
Farm size	Varied	Varied	Varied	Small	Higher in Mato Grosso	Higher in Mato Grosso
Diversified income	Varied	Varied	Varied	(High)	(Lower) in Mato Grosso	(Lower) in Mato Grosso
Education	Low	Varied	Varied	High	(Lower) in Mato Grosso	(Lower) in Mato Grosso
Network	Varied	Varied	Varied	(High)	(Higher) in Mato Grosso	Higher in Mato Grosso
Main perspectives	Enterprise, (Intermediary) domain	Enterprise domain	Enterprise, (Intermediary) domain	Enterprise, Intermediary domain	Enterprise, (Intermediary) domain	Enterprise, Intermediary domain

4 Methods

4.1 Research Approach

This section demonstrates the methodology of how the AIS framework is applied of the study. In order to provide an encompassing in-depth analysis of the prospects and obstacles of ILS innovation in Mato Grosso through the AIS framework, a qualitative analysis is conducted on qualitative document data of several case studies following the guidelines of Creswell's (2007). Data analysis of qualitative research of case studies involves interpretating findings or results which are derived from comparing findings with information taken from literature or theories. In this way, the author may suggest that findings confirm past information or diverge from it, and may suggest new questions raised by the data and analysis that were not earlier foreseen. To this end, the research adopts a case study approach using qualitative research design, which allows for in-depth investigation of contemporary phenomena in real-world contexts, especially when there is no clear boundary between the phenomenon and context of the specified topic. The case study approach facilitates the application of existing theories to analyze a certain case, allowing for in-depth investigation of processes, activities, and events of historical and contemporary phenomena. This thus enables the gathering of detailed insights into social phenomenon involving many different actors embedded in a particular social context, especially when there is no clear boundary between the phenomenon and context of the topic. The application of the AIS framework to the case study of the innovation of ILS in Mato Grosso requires a detailed description of the analytical process, which is outlined visually in Figure 4.

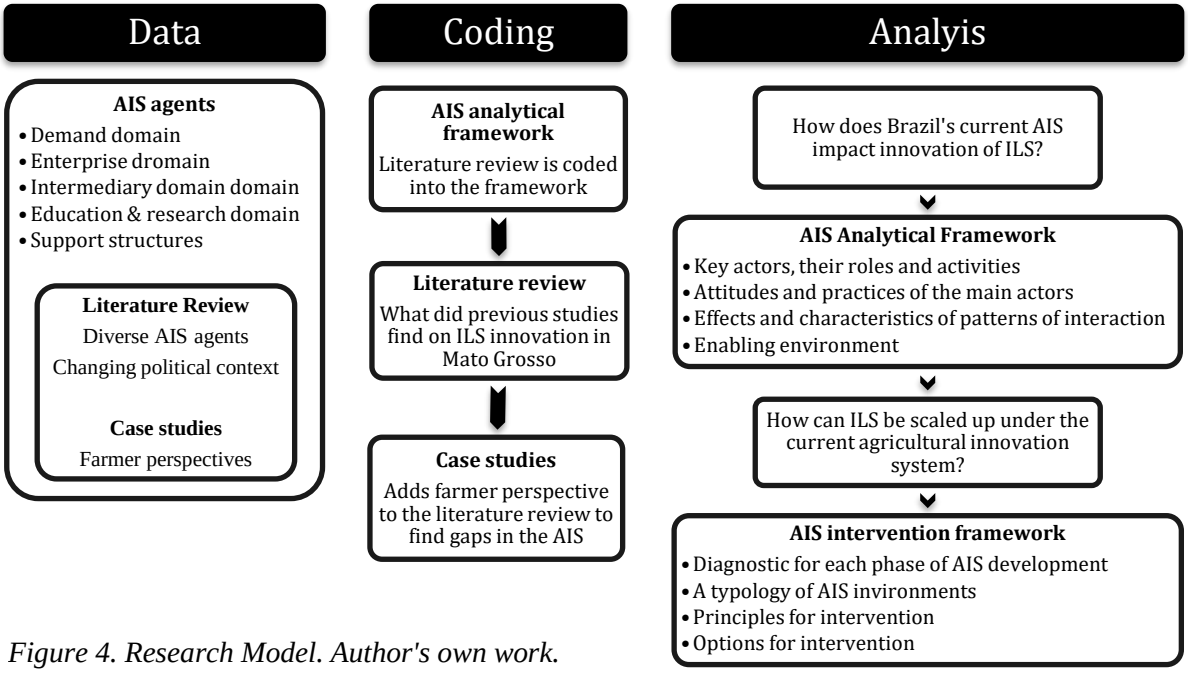

Figure 4. Research Model. Author's own work.

When qualitative researchers use a theoretical lens, they can form interpretations that call for action agendas for reform and change, and thus the qualitative research can take the form research- and action-based interpretations. The researcher recognizes that this thesis is characterized by a pragmatist worldview in its pursuit to alleviate the problems in question, which may arise out of actions, situations, and consequences rather than antecedent conditions. Instead of focusing on methods, the pragmatist researchers emphasize the research problem and uses all approaches available to understand and alleviate the problem, and is therefore not neutral in the analysis, and it is important to offer a clear overview of the step-by-step process applied in the research allowing for the reproducibility, as well as to verify its reliability, representativity, and validity of the findings. The research process presented here follows a detailed testable analytical framework, which should alleviates such concerns (Creswell, 2007). This thesis is not able to cover all aspects of the Mato Grosso's AIS involved in ILS innovation, as this is beyond the scope of this research, and thus only covers the key components of each domain in the AIS framework. However, with the perspectives attained from literature review, the thesis is able to analyze the key interactions that take place between each of the domains. The balance of different perspectives in the analysis limits its biased toward certain domains. The qualitative reliability of the findings is ensured by the adherence to the AIS framework, since it providers detailed and well-tested guidelines for the coding and analysis of case studies. The usefulness of this approach is that it combines the sporadic data from the literature review on the innovation of ILS in Mato Grosso, including the updated political dynamics, as well as the critical perspective of farmers as the final demand for knowledge in the innovation. Applying these findings with the well-tested AIS framework for designing interventions to the this case study enables the thesis to provide clear and comprehensive recommendations.

4.1.1 Application of the Analytical Framework

The objective of the first part of the analysis is to provide a description of the changing context, which reveals divergences between the innovation system and its practices, as well as to provide a description of the changing demands imposed by the context. Thus, the secondary data from the literature review is coded into the AIS analytical framework as it is described in Section 2 in order to determine the linkages and interactions between actors within and across domains, as well as institutions and policies which constitute the enabling environment for innovation. The linkages are examined in their historical and contemporary context of policy, market, and trade conditions and challenges, as well as sociopolitical environment and natural resources.

4.1.2 Application of the Intervention Framework

This part of the analysis is aimed at characterizing the circumstances and stage of innovation of the coded data in order to diagnose current and required capacities for facilitating innovation. On the basis of the diagnosis and typology of the sector, the framework suggests principles and options to guide the design of interventions which may help strengthen innovation capacity. The details on each step are covered fully in Appendix B as presented in World Bank (2006). The intervention framework is visualized in Figure 5, while Chapter 5 applies the framework step-wise by analyzing the literature review as it is informed by the analytical framework.

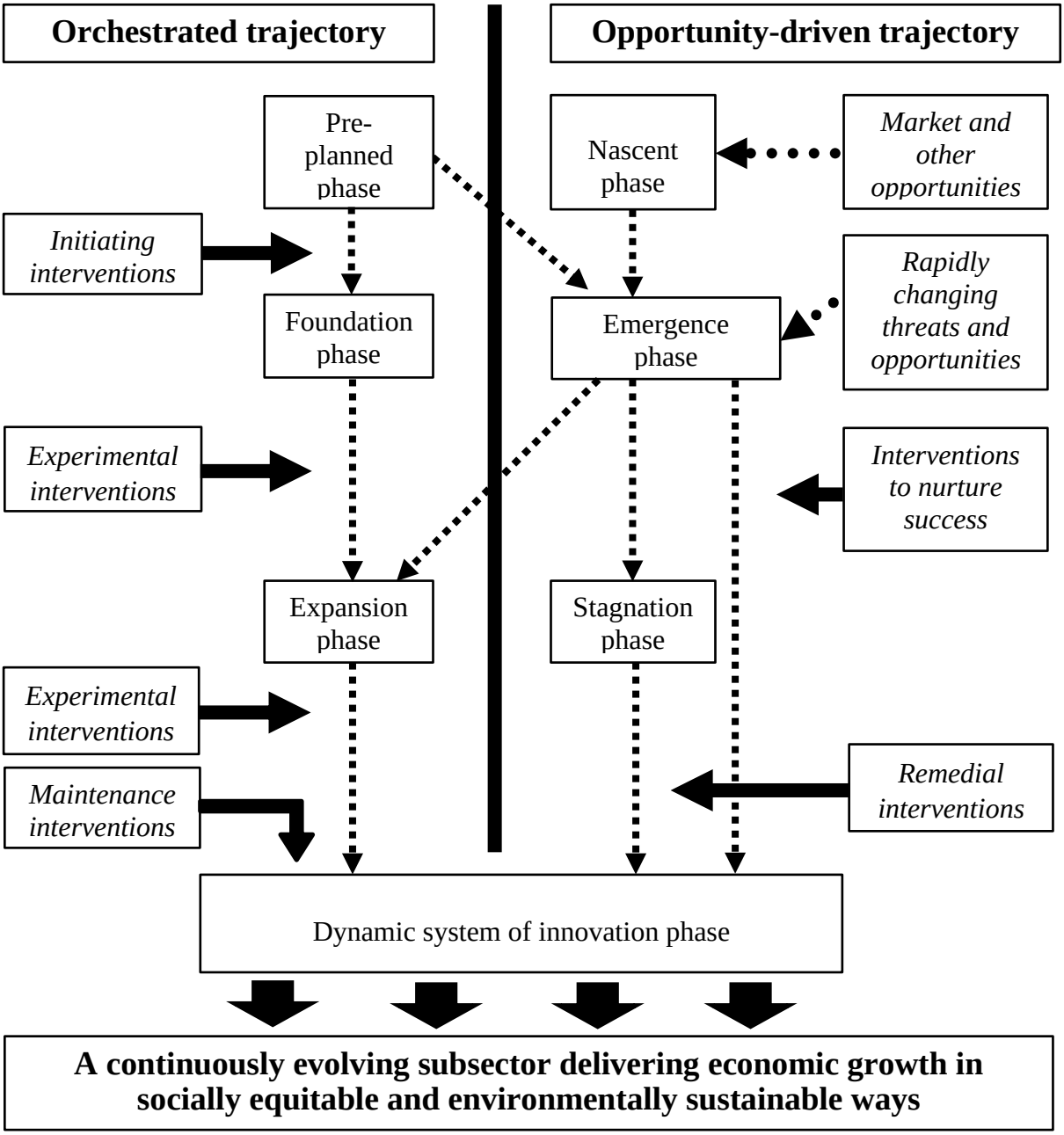

Figure 5. The intervention framework showing intervention principles for each development phase. Adapted from the World Bank (2006).

5 Emperical Analysis

5.1 Results

1.1 A Typology of the agricultural innovation phase

***The AIS of ILS innovation in Mato Grosso is in the expansion phase* (*Orchestrated pathway)*:** In the literature review we can observe that the government has identified ILS as a promising opportunity for both meeting national goals of growth in exports and reduction in rural poverty. Its interventions with projects and special programs to link different actors in the AIS have had a notable effect on growth of the innovation, even if impacts are at not at maximum potential. There is a wide range of time-bound projects and programs, of which not all have succeeded. It should be possible to identify what arrangements may lead to the emergence of a dynamic system of innovation in different settings of the specific sector, in this case the AIS of ILS. Description of the AIS below fits the expansion phase, and can be compared in Appendix B.

***Actors and roles*:** Public, private, and civil society actors with different roles form clusters centered on research or enterprise development. Sector-coordinating organizations such as MAPA, ANATER and several farmer organizations are be in place. While financial support in the form of various credit lines was available, usually from public banks or private companies, financial organizations are not playing a central part in the innovation of ILS in the system. Main actors have varying capacity to function effectively, such as the limited effect of ABC.

Attitudes and practices: Pilot interventions have enhanced the willingness to collaborate across the public and private sectors, with examples such as in Alta Floresta, Mato Grosso. However, collaboration is fragile and vulnerable to misunderstandings, which can be seen in interactions between extension services and farmers, and misalignment of research and the adoption of ILS.

Patterns of interaction: There are interactions between the main actors within the clusters, such as programs and pilot projects, but their interaction depends on public incentives and support, as public policies work in contradiction to both limit and expand the development of ILS, which can be seen in both environmental policies and recent changes, as well as the work of Embrapa and public credit lines such as ABC. Inclusiveness is still rather weak, and NGOs often cannot guarantee the participation of the poor or link with the corporate sector. Even as collaboration stretches across the domains, involvement was mainly of larger farms and organizations.

Enabling environment: Funding for research and training is in place, with many public credit lines such as ABC credit available, as well as some limited private and donation based credit. Even as there are both tax incentives for ILS and disincentives against traditional ranching, the availability of venture capital and tax incentives for innovation investments are constrained due to complex regulations and lacking usefulness of certification. The lack of a clear intellectual property rights regime is often a major obstacle for collaboration and innovation in this phase, but does not seem to be the case for Brazil, and especially for ILS as it is publicly disseminated.

1.2 Diagnostic features for the AIS development phase

The diagnostic assessment of the data assesses the characteristics, context and capacity of the AIS to reveal divergence between actors and their practices, as well as of changing demands:

Actors, roles they play, and activities in which they are involved:

- *Are active organizations from the public and private sectors sufficiently diverse?*

The AIS Mato Grosso involved in ILS is highly diversified, with a wide range of actors in the public, private and nongovernmental sectors, all serving different roles at different scales. Involvement in the demand domain is mostly dominated by the public sector with a large variety of public agencies engaged with ILS innovation. However, end consumers and retailers play increasingly large roles as production companies form sourcing policies and certifications. Organization in the enterprise domain happens mainly among farmers and corporations through development of social capital for sharing information and reaching cooperative arrangements. Organization in the intermediary domain is covered by both extension services and NGOs, while the research and education domain is mostly the focus of public research organizations, but also includes the participation of universities, NGOs, and local farmer associations.

- *Is the range of actors appropriate to the nature of the sector, the stage of development of the market, and the institutional setting of the particular country?*

As can be seen in the first stage of the analysis, the range of actors is spread across all domains, and the overall nature of the AIS development fits the expansion phase. The sector's nature, especially among farmers in the enterprise domain makes the innovation of ILS heavily dependent on the dominant involvement of public agencies throughout all stages of innovation.

Attitudes and practices of the main actors:

- *What attitudes enable or restrict collaboration between organizations?*

Attitudes of the research and intermediary domain are positive towards multi-stakeholder collaboration, and work to engage the entire sector in research, programs, and pilot projects. The attitudes of the enterprise and public sector are more mixed. Farmers and companies in the enterprise domain have an overall positive attitude towards ILS and work to establish organizations and certifications to encourage knowledge-sharing and participation in programs. Yet, the risk-averse attitudes of farmers towards ILS was the dominant cause for non-adoption, both in sticking to the practices they are used to, but also a lack of trust for the public sector, and many farmers primarily engage in knowledge sharing primarily only with other farmers. Policy-making process and agencies in the demand domain are heavily engaged and motivated in advancing collaboration across the sector, and especially on increasing farmer participation. However, the confusing legal environment is a barrier to collaboration, especially with the stances taken by the current federal government, including revisions to the Forest Code and Terra Legal government program incentivizing deforestation and traditional cattle ranching, which threatens to remove the incentive for collaboration among farmers. In spite of barriers, the attitudes have so far been overall positive toward multi-stakeholder collaboration on ILS.

- *What ineffective or conservative behavior can be identified?*

Conservative policies were already present in between the more dominant supportive policies, and the recent political context works to disincentivize ILS, and public and private funding and extension services have been criticized for ineffectiveness. In the enterprise domain farmers do see the potential of ILS, but they are risk averse and there is a cultural of traditional practices. In the research and education domain, while ILS research is a key part in the innovation of ILS, the research has limitations to its effect ineffective in that its is not entirely aligned with the types of ILS most often adopted by farmers, and tends to focus on standard variations.

- *Do patterns of trust and reciprocity exist to serve as foundations for evolving and future collaboration across the innovation system?*

Pattens of trust can only be inferred from the literature review, but it is possible to see general positive attitudes towards collaboration and inclusion across the domains, and criticism mainly focus on the ineffectiveness of different practices in reaching wide enough in inclusion. Thus, it may be inferred that trust and reciprocity lays the foundations for future collaboration.

- *Does a culture of innovation exist? Is there a demand for research in the private sector? Is there an emphasis on capacity building for future eventualities, or do organizations simply deal reactively with their present problems and opportunities? Is the use of collaborative arrangements for knowledge-based activities common? Is there an emphasis on both mastering new technology and accessing and using knowledge more effectively?*

A culture of innovation does exist, as can be seen in the broad participation in ILS innovation. There is demand for research in the private sector, even as farmers and companies often rely on word-of-mouth to engage with new knowledge. The proximity of diverse agents affiliated with research has been shown to have an effect on the engagement and adoption of ILS with farmers. In all other domains the private sector's demand of research is more established as the norm. Organization across the AIS domains mainly focus on building capacity for further innovation, as can be seen in the aims of both public agencies and private associations and corporations, research agencies and their extension services, public and private funding mechanisms, as well as public and private activities in improving infrastructure. Collaborative arrangements for knowledge-based activities do occur, as seen in the different multi-stakeholder programs, as well as on smaller scale limited to actors and organizations within specific domains. However, these are only present in some areas, and one of the main obstacles for innovation is the lack of reach and equitable access to education, extension services and multi-stakeholder programs. Lastly, the emphasis in the AIS on mastering and using ILS more efficiently is not uniform, with public effort mainly focused on maximizing the potential of the system, whereas private efforts are more diverse and practical in nature, being open to new technologies from the public, but often experiment and implement less maximized and standard ILS due to their risk-aversion

Patterns of interaction:

- *Are there networks and partnerships between private companies, farmer organizations, NGOs, and research and policy organizations?*

Networks and partnerships exist across the different AIS domains, but these are not ubiquitous, and there is room for improvement in the capabilities and scale of organizations in each domain.

- *Are the concerns of the poor integrated in the activities of the innovation systems, and are there mechanisms to promote their agenda?*

Concerns of the poor such as land tenure rights, income security, and overall lack of access to services such as knowledge, commodities, markets, infrastructure, and funding are addressed in multiple legal frameworks and programs aimed at integrating smallholders and the poor. While these mechanisms are numerous, they suffer from the overarching issue of lacking scale.

- *Are sector-coordinating bodies present or absent? If present, are they effective?*

Sector coordinating bodies are established at all levels, including both public and private agents. These have a major impact on the development of ILS, and are the basis for broad collaboration. Coordination and collaboration does occur at smaller scales without the major organizations, but on their own these have a much smaller reach and impact on the innovation of ILS.

- *Are stakeholder bodies, such as farmer and industry associations, present or absent? If they are present, what is the scope of their knowledge-based activities, such as research, training, technology acquisition, market and technology forecasting?*

As explored earlier, farmer and industry associations engage in knowledge-based activities, both in localized small scale and in sector-wide and international scales with multiple agents.

Enabling environment (policies and infrastructure):

- *Are there science and technology policies to promote collaboration (such as competitive grant funds for partnerships), to scale up innovations (such as incubators or venture capital), or to encourage private research investments (such as matching grants)?*

A wide array of science and technology policies are present in the system. The focus on scaling up innovations is mainly via funding for adoption of ILS and other environmental activities. Policies to promote collaboration and encourage private research are mainly operated via public programs with multi-stakeholder participation that supports knowledge-sharing and financing.

- *Do fiscal policies promote research and development? Are farmer and other organizations involved in defining research and innovation challenges?*

Various fiscal policies have been very effective in promoting research and development of ILS, and especially target the inclusion of poor farmers and NGOs through funding of pilot programs and individual financing of ILS experimentation and adoption. While farmer associations and NGOs are not universally involved in collaboration, their inclusion is the target of most policies their role is increasing, and their small-scale involvement in research still supports innovation.

- *Do legal frameworks exist to facilitate the application of new (international) knowledge?*

Legal frameworks do work to facilitate the application of new knowledge, especially aiming at poor farmers where adoption of ILS is generally lowest. Yet, this is where the legal framework is also the least effective, as the overall infrastructure surrounding poor farmers is also poor.

2.1 Principles of intervention

Interventions that help build on or nurture success should be applied to the AIS of Mato Grosso which work to expand proven initiatives, strengthen good practices, and address weaknesses, in order to transition from the expansion phase to a dynamic system of innovation, where as continuously evolving and balanced subsector of ILS innovation delivers economic growth in socially equitable and environmentally sustainable ways.

2.2 Options for intervention

Intervention principles: Interventions for the AIS in the expansion phase should focus on identifying and further expanding the mechanisms and initiatives that have proved to work. Since funding for research and industry collaboration has been effective, but lack proper scale, interventions should expand these mechanisms under the theme of ILS and forest conservation by strengthening existing good practices and address emerging weaknesses in the mechanisms. Possible intervention into the AIS of Mato Grosso to scale up the innovation of ILS include:

- *Revitalize NGO networks, with a focus on learning and capacity building.*

Since there is already a precedent of NGO networks working in learning and capacity building in the AIS, and thus public efforts to increase these mechanisms should expand existing programs or develop additional multi-stakeholder pilot programs to reach into the poor areas.

- *Expand consortia-based research funding for topics where interaction between private companies and research organizations is important.*

In order to alleviate the gap between research and application of ILS, research funding should increase its focus on knowledge-sharing between public research institutions such as Embrapa, NGOs and local farmer associations, especially in areas with poor farmers with low adoption.

- *Provide matching grants to support private sector investments in research.*

Since experimental research is already being carried out locally by farmers and companies, these activities should be incentivized alongside incentives for ILS adoption in the existing ABC credits and other underutilized funding mechanisms which currently focus on adoption.

- *Create or strengthen a sector-coordinating body with members from the public sector, private sector, and NGOs and representatives from major markets.*

Existing coordinating bodies such as SEMA and SEDRAF, NGOs, and farmer organizations, need to be strengthened in their collaboration in policy and program design. Such intervention should come from the government, and could be implemented at state and/or municipality level.

- *Establish training and research facilities jointly sponsored and governed by the public and private sector, perhaps including postgraduate programs.*

While the existing extension services and training programs are to some extent multi-lateral, they need to be upgraded in terms of stakeholder participation, and should be further extended in order to encompass more rural farmers and associations. Sponsorship for these developments could come a refocusing away from traditional practices in existing funding such as ABC credit, while private funding could be organized through existing NGOs and REDD+ mechanisms.

- *Change university curricula and involve the private sector in university governance.*

Interventions into university curricula should encompass perspectives of farmer associations and NGOs alike to ensure research and education on ILS is in line with the realities of practice.

- *Establish internships/exchange with industry, universities, and coordinating organizations.*

The focus of internships should be extended to incorporate rural areas in order to ensure the proliferation of skilled labor to overcome the adoption barrier of lacking of lacking workforces.

- *Establish mechanisms for quality and trade certification, and create advisory capacity for achieving compliance.*

Existing mechanisms of certification for good practices from private company associations and public certificates from the Forest Code and Embrapa must be improved in terms of recognition. This could be achieved through increased market promotion to strengthen its impact, but this will only be successful if coupled with improved effort in compliance with requirements, which can be achieved with the aforementioned expansion of extension services and funding access.

5.2 Discussion

The findings from the literature review have answered the first research question in finding that the AIS of Mato Grosso has gone through remarkable development resulting in increased attention to environmental issues, which has increased the incentives for participating in the innovating of ILS for actors and organizations across the sector. Several positive interactions that worked to improve the innovation of ILS were identified, along with shortcomings and future potential issues, which would need to be addressed. Then, based on these findings the interventions framework identified the typology of the AIS as being in the expansion phase of the orchestrated trajectory, which allowed the analysis to diagnose the strengths and weaknesses of the AIS in developing the capacity for ILS innovation. Finally, the principles and options for intervention developed for the expansion phase were applied to the specific needs of the AIS. The typology of the AIS appears to be in the early stages of the expansion phase, as most of the mechanisms in place, but are still underdeveloped, and thus the road to a dynamic phase is long. The results of the analysis follow the same overall sentiments from the literature review, both in terms of diagnosis and policy recommendations, especially the focus on expansion of existing mechanisms and the refocus on poor farmers. This was to be expected given the nature of the methodology, however, the application of the AIS framework to investigate the different aspects of ILS innovation in Mato Grosso is a novel approach. Thus, the results of this thesis provide a holistic view of the different aspects, and can thus present more directed interventions.

6 Conclusion

6.1 Research Aims

Considering the precarious state of affairs regarding the deforestation of the Brazilian Amazon, the aim of this thesis was to examine the prospects and obstacles faced by the innovation of ILS in the state of Mato Grosso, Brazil. Specifically, the aim was to investigate how the AIS in Mato Grosso impacted ILS innovation and to suggest interventions to scale up ILS innovation. The scope of this research is both historical in its context, and contemporary in its interventions.

6.2 Research Objectives

The research objectives were then to first investigate how Mato Grosso's AIS has impacted ILS innovation by applying the AIS analytical framework to the findings in a literature review of previous studies on the topic. The second objective was to apply the intervention framework to the analytical framework of the literature review, in order to identify the typology of the system, and diagnose the AIS for strengths and weaknesses, to which the analysis suggested interventions for scaling up the innovation of ILS based on principles for the specific typology.

6.3 Practical Implications

The typology of the AIS appears to be in the early stage of the expansion phase, even if most of the mechanisms for developing the systems capacity for ILS innovation are already in place. As such, the analysis of the intervention framework suggested interventions which focused on expanding the existing positive mechanisms which support ILS innovation with a focus on increasing multi-stakeholder collaboration in areas such as research, knowledge-sharing, education and training, and funding, while refocusing resources away from traditional practices in cattle ranching to further increase the effectiveness of efforts across the domains oft the AIS. Overall, the findings follow the a similar sentiments as the literature review, both in terms of diagnosis and policy recommendations, especially the focus on expansion of existing mechanisms and the focus on further inclusion of poor farmers. However, the application of the AIS framework to investigate the aspects of ILS innovation in Mato Grosso is a novel approach, and the results of the analysis provide a holistic view of the different aspects in ILS innovation based on the well-tested AIS framework, which is designed specifically for such interventions. The recommendations of this thesis are thus somewhat more inclusive than previous studies.

6.4 Future Research

Future research could attempt to replicate this study by use of primary data from each domain, which would allow for more in-depth examinations of the different interactions in the AIS. Also, future research could add additional focus to the impact the changing political context, as the effects are not yet fully known, but are likely to influence future interventions in the AIS.

6.5 Chapter Summary

The introduction showed the precarious state of affairs in the Brazilian Amazon rainforest, particularly in Mato Grosso, where unsustainable cattle ranching is driving the deforestation. Since the economy of Brazil as well as the world's development is dependent on beef exports, Brazil needs to invest in sustainable development of its cattle production without deforestation. Integrated Livestock Systems is a technology which serves this purpose well, but as of yet occupies only a small part of the Brazilian Agricultural Innovation system. The AIS framework has been developed specifically to investigate the AIS of developing countries like Brazil, and to can be used to suggest suitable interventions. The literature review found that overall the AIS of Mato Gross involved in ILS innovation is highly diversified, with a wide range of actors in the public, private and NGO sectors, with collaboration between stakeholders across the AIS. However, there are still several challenges in the AIS, especially in the scale and focus of areas such as research, knowledge-sharing, education and training, funding and infrastructure, with a special focus on the role of small farmers as the frontier of adoption of new ILS technologies. As such, recommendations from the literature review have focused mainly on the above issues. In order to examine the prospects and obstacles of the innovation of ILS in Mato Grosso, Brazil, this thesis mainly relies on secondary data on ILS innovation derived from the literature review. The AIS framework is designed to source its information from available empirical material, such as earlier studies exploring science, technology, and innovation policy issues in the sector. Thus, secondary data on each domain of the AIS analytical framework is covered in the literature review with empirical data from academic research, and reports from different actors, in order to determine linkages and interactions between actors within and across AIS domains, as well as institutions and policies which constitute the enabling environment for innovation. The analysis then applied the intervention framework to characterize the circumstances and stage of innovation of the coded data in order to diagnose current and required capacities for facilitating innovation. On the basis of the diagnosis and typology of the sector, the framework suggested principles and options for interventions to strengthen systemic innovation capacity. The analysis found that the AIS typology appears to be in the early stage of the expansion phase, yet most mechanisms for developing system capacity for ILS innovation are already in place. As such, the analysis of the intervention framework suggested interventions which focused on expanding the existing positive mechanisms which support ILS innovation with a focus on increasing multi-stakeholder collaboration in areas such as research, knowledge-sharing, education and training, and funding, while refocusing resources away from traditional practices in cattle ranching to further increase the effectiveness of efforts across the domains oft the AIS.

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8 Appendix

8.1 Appendix A: Case studies

8.1.1 Case Study 1: Cotriguaçu Green Municipality Program

The data from Guerra et al (2014) examines the effects of Cotriguaçu Sempre Verde (CSV), led by the Instituto Centro de Vida (ICV), an NGO initiative promoting socio-economic development through conservation and sustainable management of natural resources in the municipality of Cotriguaçu in northwestern Mato Grosso. The initiative has focused on helping farmers comply with environmental regulations and adopt more sustainable practices, by engaging with and building confidence among indigenous groups, cattle ranchers, loggers, small farmers and the municipal government of Cotriguaçu.

Data Sample and collection

The data sample from the case study reports results from a 2011 survey of 122 households in four communities in the three land reform settlements included in the CSV intervention area. Collection of data was completed with a random sampling of names from a complete list of households living in each community attained from the local health agent and/or local leaders. The 122 randomly selected farms (~30 per community) were interviewed in March-April 2011. Since the survey concerns a specific area in Mato Grosso, it is important to evaluate the characteristics of the surveyed farmers, in order to determine the comparability with other data. The three land reform settlements of the study area: Projetos de Assentamento; Juruena, Nova Cotriguaçu; and CEDERES II make up 14% of the land area of the municipality of Cotriguaçu. Education level in the study area was general lower than national average, and there was high variation in total household income among communities, with as much as total 50% difference. In communities with average higher income the average land holding was the smallest and with significant conflicts over land tenure, with more diversified income sources. Small farmers in the study area are generally considered the most disadvantaged people in the municipality. Cattle ranching was the most important economic sectors are, as well as forestry, timber, agroindustry and small-scale agriculture, accounting for more than 34% of the total income of households study area, followed by wage labor, other and crops at 16% each. Deforestation was increasingly driven by farmers shifting into cattle ranching and reducing their reliance on crops.

Data evaluation

The data should be reliable as it through the survey provides direct information on the perspectives of the enterprise and intermediary domain of Mato Grosso. The random sampling provides a representative example of the enterprise domain from the particular perspective of the farmers from the poorer areas. While the study does not focus specifically on ILS innovation, but instead the more general sustainable agricultural practices in the study region. However, the majority of farmers in the sample were primarily engaged in unsustainable livestock production, while the focus of the CSV programme was on promoting sustainable agriculture practices. The data is thus a good proxy for the early socio-political context of ILS innovation, which may provide the analysis with a historical component the analysis of early interactions between the enterprise and intermediary domain, as well as actors of other domains.

8.1.2 Case Study 2: Adoption and development of ILS

The data from Gil et al (2015) assesses all identified ILS initiatives by 2012/13 in Mato Grosso, which were mapped and described in terms of their technical and non-technical features, and then combined with farm survey data set to provide a detailed account of the various technologies being disseminated, individual diffusion levels and potential adoption constraints. The results generated via qualitative and quantitative research methods provides an overview of ILS practices, farmer perception of such technology and insights into future prospects.

Data sample and collection

Gil et al (2015) collected the data through a survey (2012/2013) with 134 farmers from 141 municipalities in Mato Grosso, of which were 61 ILS adopters and 73 nonadopters, covering the ILS types defined in the National Policy for Integrated Crop–Livestock–Forestry Systems (Federal Law n. 12805/2013): iCL: crop–livestock systems - grains, grasses, animals (89%); iLF: livestock–forestry systems - grasses, animals and trees (5%); iCF: crop–forestry systems - grains and trees (1%); iCLF: crop–livestock–forestry systems - trees, grains, grasses, animals (5%). The survey contains data on ILS farmers and two types of non-ILS adopters: soy producers and cattle ranchers. The ILS adopters in Mato Grosso were identified by contacting unions, professional associations, rural extension services and consultants in every municipality of Mato Grosso, from about half were randomly selected for interviews, while ensuring that the four types of ILS are represented proportionally to their occurrence. The non-adopters were likewise selected from the same municipalities as the selected ILS-adopters to reduce the standard deviation of their answers, with priority given to soya producers and cattle ranchers. The survey concerned five general categories of adoption determinants: socio-demographic characteristics of farmers; resources availability; market incentives for/against adopting ILS; farmland bio-physical factors; risk and uncertainty in the market and institutional environment. Secondary data was sourced from scientific literature or other studies by local organizations: FAMATO, APROSOJA, ACRIMAT, FASE, IMEA, UFMT, Embrapa Agrossilvipastoril, Local NGOs involved in the establishment of ABC Plan (IPAM, ISA, TNC), EMATER, Secretariat of Agriculture, Secretariat of Environment and unions, Secretariat of Agricultural Development and Cooperatives (SDC – MAPA), EMBRAPA's head office in Brasília, Ministry of Environment, financing institutions (BNDES, Banco do Brasil and Rabobank- Brazil).

Data evaluation

Generally, the ILS initiatives covered in the survey are of interest to the purpose of this study, with the exception of iCF (crop–forestry systems). However, since iCF makes up only 1% of adopters, their effect can be ignored in the analysis. The data in the case study is reliable, since the information is gathered directly from the farmers and other actors. Also, the comprehensive and random sampling of the data ensures its representative of ILS initiatives in all of Mato Grosso. Since the data covers a comprehensive examination of the characteristics of all adopters, including their interactions with all other AIS domains, it is assumed that the data represents the general cattle producer in Mato Grosso, including ILS adopters and non-adopters. The data thus forms a valid basis for the AIS analysis, providing a general picture of the perspective of the enterprise domain to which insights of the other case studies are aggregated.

8.1.3 Case Study 3: Determinants of ILS Integration

The case study by Gil et al (2016) examines the determinants of ICL adoption in Mato Grosso, and comprises two typical cases of ILS in Mato Grosso: the rotation of soy and pasture, and the rotation of soy followed by maize and pasture. The study includes a variety of factors (biophysical, socioeconomic, and institutional) which are observable at the farm and/or municipality levels that may influence the wide-scale occurrence of ILS.

Data sample and collection

In order to analyze ILS occurrence at the household and municipality levels in Mato Grosso the case study used the same primary dataset as Gil et al (2015) using the sample sampling method. The original database was updated with information obtained from Mato Grosso's Institute of Agricultural Economics (IMEA) and Observatorio ABC, a think tank monitoring the ABC Plan. The survey included 145 interviews of which 54 were ILS adopters, 59 were specialized soy farmers and 32 were cattle ranchers. Survey respondents were asked about their personal preferences, resource endowments, tenure rights, farm characteristics, membership to cooperatives and professional associations, as well as access to credit, information and technical assistance. The data covering for the municipality level analysis covers all 141 municipalities of Mato Grosso, and was gathered from databases and websites, and academic research.

Data evaluation

Since the data comprises the same dimensions as that of case study 2 it follows the same reliability, representativity and validity for use as the basis for analyzing the AIS framework. Notably this case study adds the dimension of aggregated municipality level findings by checking for differences between characteristics at the levels of household and municipality, which allows for useful contextual insights into the factors of ILS innovation at different scales. However, overall the similarities in sample perspectives of case 2 and case study 3 provide the same insights of diverse farmers for the aggregate comparison of the enterprise domain.

8.1.4 Case Study 4: Improving Land Management

The case study by Latawieca et al (2018) examines the underlying factors which support or inhibit improvements to land management of farmers in the Amazon biome of Mato Grosso. More specifically, the main focus of the study is on cattle ranchers and other stakeholders such as local NGOs implementing programmes on better land management which fall under Embrapa's Good Agricultural practices (GAP) protocol of improved cattle management: management of rural property, social function of rural property; of human resources; of environmental; of rural facilities, pre-slaughter and animal welfare; of pasture, supplemental feeding, animal identification, sanitary control, and reproduction. The GAP practices, which thus include ILS practices, are used in the study as a proxy for better cattle land management.

Data sample and collection

The data sample includes semi-structured interviews (2013-2015) with diverse farmers from the Amazon biome of Mato Grosso, focus groups of GAP adopting farmers from the municipality of Alta Floresta in Mato Grosso, and non-farmer stakeholders associated with the cattle production chain (local farmer association, local government, and a technical assistance). First, the study developed pilot questionnaires (N=5) based on consultations with local farmers in order to maximize the study's relevance to local conditions and issues related to the adoption. To design a robust research approach with credible and comprehensive data, local stakeholders were consulted, including local NGO members, researchers, farmers and technical assistants. The focus groups included 25 farmers as well as stakeholders with implementation experience, and were used for understanding farmers' perspectives regarding barriers to GAP adoption, exchanging knowledge on GAP adoption amongst farmers, and developing a broader survey for the 250 farmers. The 250 farmer sample has a relatively even distribution of large and small properties, with the average farm size ~60% smaller than the average of Mato Grosso, with ~60% being adopters and ~40% being evenly distributed among non-adopters and no answers. This distribution is intentional to ensure a varied sample, while ensuring it contains GAP info. Finally, the 250 farmers sample has an education level higher than average for Mato Grosso. Higher than average income levels is inferred from the smaller farm size and higher education. Thus, focusing on adopters, the study includes focus groups (N=25), data validation events (N=23), as well as interviews: semi-structured interviews (N=250), follow-up structured interviews (N=82), and stakeholder semi-structured interviews (N=17). The semi-structured interviews investigated: Background information (location, size of farm and pasture area, stock size, degraded area, education, and age); Good agricultural practices (knowledge of different GAP, level of adoption of GAP, and willingness to adopt ILS practices); Barriers to adopting GAP; Forest conservation and management (farm forest cover, benefits, reforest intentions).

Data evaluation

The usage of in-depth interviews of farmers and stakeholders should form reliable evidence of farmer and stakeholder perceptions of the factors influencing adoption of ILS practices. Also, the inclusion of adopters and non-adopting farmers, focus groups and stakeholders allows for the data to be representative of the different perspectives of the enterprise domain and the intermediary domain. The focus on diverse farmers of both adopters and non-adopters allows for broader insights into the enterprise domain. It is important to note that the data mainly represents the Amazon biome of Mato Grosso, and thus provides a specific geographical context which adds to more complete aggregate of the enterprise domain in Mato Grosso.

8.1.5 Case Study 5: Results from On-The-Ground Efforts to Promote Sustainable Cattle Ranching in the Brazilian Amazon

The case study by Zu Ermgassen et al (2018) investigates six initiatives of sustainable cattle ranching in the states of Mato Grosso, Pará, Acre, and Amazonas in the Brazilian Amazon, which successfully improved cattle productivity while complying with Brazil's Forest Code. The study focuses is on factors which influenced adoption, and differentiates practices of cattle ranching for production of either beef or dairy intensification from the different states, the results of which are evaluated both independently from the different states and aggregated.

Data sample and collection

The data consists of six initiatives of sustainable cattle ranching surveyed in 2012-2015. Specifically, the initiatives in Mato Grosso was located in the municipalities of Alta Floresta, Nova Canaã do Norte, Paranaíta, and Cotriguaçu amount to 23 farms and include a range of general ILS practices, as well as the application of GAP. The 13 farms of the Mato Grosso sample have a total of 23,800 cattle, with a mean farm size of 200 hectares (30–900 hectares), of which 14,300 hectares are under ILS. The 4 initiatives from states of Pará and Amazonas make up a combined 40 farms (6-13 farms per initiative), and include a range of general ILS as well as GAP practices. The largest initiative in Pará has a total of 34,043 cattle on an average 3,077 hectares (100–6,900 hectares), of which 20,208 hectares are under ILS. The smallest initiative in Pará has a total of 145 cattle on an average 83 hectares (25–200 hectares), of which 50 hectares are under ILS. The initiatives in Amazonia are in between. However, the sample of Acre state initiatives (2014) add up to 6400 farms, but contain no data on farm characteristics. The data was collected in 2015 using a questionnaire about the financial and production performance of ILS initiatives, and was shared with the representatives of four organizations (The Nature Conservancy, Instituto Centro da Vida, Embrapa, Idesam, and Florestas de Valor). Two versions of the survey were circulated, one for beef and one for dairy intensification: overview of the project; characteristics of the initiative; details of the practices implemented on participating farms; the costs involved in the implementation of improved farm management; the costs involved in maintenance of improved pasture; the productivity achieved on the farm; details of other measures of performance; and details of farmers recruitment to each initiative and the respondent's reflections on the barriers and opportunities for improved cattle ranching. Survey data was complemented with published results from initiatives where it was available.

Data evaluation

Consisting of both interviews with farmers and consultations from stakeholder organizations, the data provides reliable evidence of the farmer perspective of the enterprise domain as well as some contextual perspectives of the other the AIS domains. For the purposes of this paper, only the data which represents the perspectives of farmers in Mato Grosso is applied to the analysis. The data should be representative of the enterprise domain of Mato Grosso, as well as the intermediary domain, with the caveat that the geographic scope and sample size from the state is relatively small, and mostly represents wealthier, more well-connected farmers. Thus, the data thus supplements perspectives of the previous cases with an oppositely biased sample.

8.1.6 Case Study 6: Perceptions of Integrated Crop-Livestock Systems for Sustainable Intensification in the Brazilian Amazon

The case study of Cortner et al (2019) examines the perceptions of farmers, agribusiness professionals, extension agents, and researchers regarding ILS in the Brazilian Legal Amazon. In order to better illuminate what concerns besides agronomic and economic outcomes might guide farmers' decisions to adopt ILS, the focus of the case study was on the degree to which structural factors interact with personal experiences to shape information and values and farmers' understanding of the costs and benefits of adopting ILS practices.

Data sample and collection

Four rounds of detailed interviews were conducted in between 2014-2018 across the states of Mato Grosso, Acre, Pará, and Rondônia (33% in 2014, 33% in 2015, 7% in 2017, 27% in 2018), with very little difference in the proportion of adopters to non-adopters over each time period. The interviews were conducted with farmers known to Embrapa or identified by local syndicate, from whom additional farmers with similar or different management and background profiles were identified until the sample consisted of farmers across a range of characteristics and there were no new themes brought up by the farmers. The resulting qualitative dataset consists of 64 interviews, including 33 interviews with farmers (a total of 536,527 hectares) and 31 experts. Of the 33 farmers 18 were ILS adopters, while 15 were non-adopters, both focusing on cattle. The study focused on ILS systems without forestry practices as it is dominant in the study area. In general, the adopters in the sample had larger farms, greater access to off-farm income, higher participation in agricultural groups, and more commonly held community leadership. The farm sizes of the sample (all four states) ranged from 26 to 359,877 hectares with a median farm size of 1900 hectares, which is larger than the average farm size in the Brazilian Amazon. Most adopters were practicing ILS on a small part of properties (median 33% of pasture area). For 80% farming was the primary income, while 48% of farms also had off-farm employment. Specifically to the Mato Gross region, the sample had 9 farms with a total of 376,908 hectares, with a median pasture area was 1110 hectares, on which the a median 950 hectares had ILS. The Mato Grosso sample had an average proportion of membership of agricultural organization, the lowest proportion of off-farm income, and the highest proportion of leadership positions. The time gap between rounds allowed the survey to identify more adopters than were available in the first period, and to see how key themes and ILS diffusion evolved across the study area. This sampling strategy was used due to the relative low number of adopters in the sample and to obtain a cross section of adopters and non-adopters with a variety of characteristics. Interviews were open-ended, and asked: *Do farmers and local experts believe ILS can address important local livelihood concerns? What barriers have farmers encountered in adopting? What enabling conditions (policies, market opportunities, knowledge, and assistance) could further facilitate ILS adoption?* The characteristics of the farmers and experts are as follows: The first group consisting of agricultural producers and local experts, the latter composed of researchers, agricultural input vendors, consultants, and producer cooperatives or syndicates.

Data evaluation

Since the case study consist interviews from both farmers and experts, it provides reliable evidence for the direct attitudes and practices of the demand and intermediary AIS domains, as well as indirect evidence for the interactions with other domains. The study includes a gradients across the four states, including Mato Grosso, with differences in perceptions of ILS across regions which yield different challenges, opportunities and incentives for adoption. For the purposes of this paper, only the data focuses on Mato Grosso is used to be representative of actors involved in both cattle ranching and ILS initiatives in Mato Grosso. The study sample is rather small, and is biased toward larger, wealthier, and more well-connected farmers. On its own it is thus not representative of the entire population of farmers in the study region, but includes the perspectives of said wealthier farmers, which in combination with the other case studies forms a more complete picture of the enterprise domain and intermediary domain for the AIS analysis.

8.1.7 Generalization of the Case Studies

In order to code the perspectives of case studies into themes fitting the AIS framework, the different case studies were compared according to characteristics of the sample in each case. Qualitative generalization is applied to the coding process of the case studies, not with the intent of generalizing the findings to a context outside of those under study, but instead generalize across the particular descriptions and themes developed in the contexts of the different cases. The generalizability of qualitative research which inquires several cases can be generalized to some broader theory, however, to generalize the findings across settings requires good documentation of qualitative procedures of details and development of the case study database.

Thus, the characteristics of the case studies were compared to find the extent of generalizability of the findings from the different case studies to the AIS analytical and intervention framework. The focus of the comparison was the geographic and temporal scope, sample size and contents, as seen in **Error! Reference source not found.** in section 3. *Geographic scope:* Case studies w ere compared according to which parts of Brazil they covered in the survey of ILS initiatives. Case 1 covered a only single municipality in Mato Grosso, whereas cases 2 and 3 covered the state of Mato Grosso. Case 4 covered only the Amazon biome within Mato Grosso, where case 5 and 6 covered Mato Grosso and other states in the Amazon biome. *Temporal scope*: All case studies cover surveys from roughly the same time. *Sample size and contents:* Regarding sample size the cases 1, 2, 3, 4 had large sample sizes, whereas case 5 had a smaller sample size, and case 6 had a small, detailed sample size, but with a significantly larger aggregated sample. All cases contained perspectives of both enterprise and demand intermediary domains, and less detailed perspectives of the other AIS domains. Regarding characteristics, i.e. practices, farm size, income, education, network, all cases were roughly similar when accounting for the geographic scope of the case studies.

Based on the comparison, the results from case 2 and 3 are generalized to form the baseline of the analysis of Mato Grosso, while results from case 1 is used for contextualization of the perspectives of poor farmers and high stakeholder interaction, case 4 is used for contextualization of the richer, more diversified and well integrated farmers with high stakeholder interaction, and lastly cases 5 and 6 are generalized to compare the applicability of the findings from Mato Grosso to the AIS of wider Brazilian Amazon biome. Additionally, the supplementary empirical data is generalized based on the virtual identicality of their sources and findings. Thereafter, with the data generalized according to the overarching themes and perspectives, coding of the findings is conducted according to the AIS analytical framework, whereafter the coded findings are analyzed according to the intervention framework.

8.2 Appendix B: Full Intervention Framework

1.1 A typology of the agricultural innovation environments

Pre-planned phase (Orchestrated): In this phase new opportunities have yet to be identified. Local expertise is available, but producers and entrepreneurs are not sufficiently linked to jointly evaluate market trends and identify emerging opportunities. Research and other policy interventions focus on traditional agricultural commodities. This stage is essential for building a critical mass of agricultural scientists, but does not lay the foundation for a sector to take off.

- *Actors and roles:* Public research and training organizations and private actors are present, but focus on the traditional agricultural priorities. Intermediary organizations that link actors, broker partnerships, or provide access to new knowledge and information are absent.
- *Attitudes and practices:* Research organizations have an ivory tower tradition. The public and the private sectors work independently of each other, and trust remains limited.
- *Patterns of interaction:* Interaction among actors is structured around traditional sectors: research links to farmers via agricultural extension arrangements; there is little interaction between research and the private sector; the private sector interacts with government mainly via political lobbying. Public and private sectors have poor access to information about emerging markets and other opportunities, which restricts them from sharing knowledge.
- *Enabling environment:* Generic research and training provisions might be in place, but measures in support of a specific sector are not, because the opportunities have not been identified. Financing mechanisms for innovation are usually absent.

Foundation phase (Orchestrated): Sectors and commodities are identified and supported by public research and policy interventions. This phase is characterized by significant investment in research over an extended period, where the main tools for stimulating innovation have been investments in research, development of technologies, and training. However, the effect of these efforts on growth has been the limited. For example, the demand for livestock products may be growing rapidly, but livestock research has not yet had a strong impact on the sector. The private sector has begun engaging in new opportunities, but with limited effect on growth. While the sector's foundation for growing innovation may be in place, the necessary patterns of interaction between research, the private sector, and other actors do no yet exist.

- *Actors and roles:* Government and research and development organizations have chosen priority themes or established specific programs. While new technologies may have been developed, they have not been adopted by farmers or entrepreneurs. Entrepreneurial activity is already greater than in the preplanned phase. Companies are exploring new opportunities identified by the public sector. Intermediary organizations that could link the actors are either absent or weak. Financial organizations do not play an effective role.
- *Attitudes and practices*. Research systems are compartmentalized, hierarchical, and not conducive to interdisciplinary collaboration. The public and private sectors have little trust in one another or practice in working together.
- *Patterns of interaction*. Interaction remains within each sector and does not cross the public-private divide (for example, research agencies collaborate with extension agencies but not with input suppliers). This is likely to be the main constraint to innovation in this phase.
- *Enabling environment*. Primarily supply-driven public research and training arrangements are in place. Incentives for entrepreneurial activity may also be in place, but the financing of innovation may still be a bottleneck.

Expansion phase (***Orchestrated)***: In this phase the government has identified a few promising opportunities for meeting national goals of growth in exports or a reduction in rural poverty, and intervenes with projects and special programs which help link different actors in the IS, now having a notable effect on growth. There is a range of time-bound projects and programs, not all of which succeed. It should be possible to identify what arrangements may lead to the emergence of a dynamic system of innovation in different settings of the specific sector.

- *Actors and roles*: Public, private, and civil society actors, each with different roles, have formed clusters, which are typically centered on research or enterprise development. Sector-coordinating organizations, usually established with government support, may be in place. Financial organizations are often not yet included in the innovation system. It is increasingly clear that the main actors have varying capacity to function effectively in their roles.
- *Attitudes and practices:* Pilot interventions have enhanced the willingness to collaborate across the public and private sectors, but the practice of collaboration is still fragile and vulnerable to misunderstandings.
- *Patterns of interaction:* The main actors within the clusters interact, but their interaction still depends on public sector incentives and support. Inclusiveness is still rather weak; for example, NGOs often cannot guarantee the participation of the poor, or an NGO-led cluster-network usually does not link with the corporate sector.
- *Enabling environment:* Funding for research and training is in place. The availability of venture capital and tax incentives for innovation investments may be constrained. The lack of a clear intellectual property rights regime may hinder collaboration and innovation.

Nascent phase (Opportunity-driven): The system resembles the pre-planned phase of the orchestrated trajectory, but the private sector is more proactive. Companies, entrepreneurs and sometimes NGOs may have started recognizing innovation opportunities or opportunities for transforming traditional sectors, and because local expertise and actors are present, some initiatives result in new markets. However, the government is unaware of these promising opportunities, and a recognizable sector has yet to emerge.

- *Actors and roles:* The main actors consist of a small number of producers, entrepreneurs, or NGOs that have recognized new opportunities. Traditional public research organizations may be in place.
- *Attitudes and practices:* The entrepreneurs involved display strong risk-taking and opportunity-searching behavior.
- *Patterns of interaction:* Entrepreneurs have sufficient local links to gain information about emerging markets and other new opportunities but have not developed any networks within the sector.
- *Enabling environment:* Public research and training programs may be in place but are not focused on the new opportunities.

Emergence phase (Opportunity-driven): The sector is now established with activities of the private sector or NGOs driving rapid growth, and starting to be recognized by the government. Companies or individuals in follow a leading pioneer by means of imitation or improvement. Competitiveness is the main driver of low prices. Consumer demand and market standards quickly increase the pressure to innovate, and thus this phase is usually brief. However, interventions may still be important. Networks that could respond to the new conditions through innovation are often missing, and the sector is thus in risk of becoming stagnant.

- *Actors and roles:* Entrepreneurs dominate the system and gain access to new technology through their own knowledge or through informal networks. Technical expertise might be purchased from private providers, while public research plays a traditional, limited role. Additionally, farmer and industry associations may have been established.
- *Attitudes and practices:* The business community has no tradition of paying attention to social and environmental considerations, nor has it much trust in or experience in partnerships with the public sector. Quality and environmental standards may exist but are usually unenforceable.
- *Patterns of interaction:* Despite good informal local networks, entrepreneurs hardly interact with the research and policy-making communities. Poor links between industry and research organizations create a circle of weak demand for research. As low prices are the main source of sector competitiveness, sector upgrading and creation of national brands get little support. Industry associations, if any, focus on lobbying for policy change.
- *Enabling environment:* The enabling environment is usually quite weak. Research, training, and financing organizations do not focus on the needs of the sector. Policy makers are only just starting to recognize the importance of the sector.

Stagnation phase (Opportunity-driven): In this phase the sector faces increasing pressures to innovate due to changing consumer demands and trade rules, and competition, especially internationally. Traditional sectors often get stuck in phase, and newly emerged sectors quickly enter this phase. Under emerging constraints actors often fail to innovate or take advantage of new opportunities, and there is limited capacity to deal with social and environmental concerns of their activities. Government and donor support for the sector has varying degrees of success, usually addressing problems haphazardly rather than building a sustainable innovation capacity.

- *Actors and roles:* Multiple actors have become well established but often entrenched. Entrepreneurs and traditional farmers play a large role. The public sector has recognized the sector and provides support. Civil society organizations may have become active, but they often get mired in a technology transfer role. Coordinating bodies, often established by the public sector, are frequently ineffective. Industry associations (established, for example, to deal with marketing and political lobbying for policy change) may be unable to expand their scope to promoting innovation.
- *Attitudes and practices:* Most actors have become effective in their initial roles but face difficulties in transforming their practices to respond to new situations. The focus of industry associations on marketing or lobbying for policy support restricts their ability to engage in technological upgrading. The regulatory focus of public coordinating bodies restricts their ability to act as troubleshooters. Public research programs are in place but are poorly articulated with the farm and business community; as result, research is often considered irrelevant. Interventions focus on technical assistance and problem solving and less on creating capacity to anticipate and deal with new problems.
- *Patterns of interaction:* Collaboration among the multiple actors is weak. Private sector linkages with the research and training community are still poor; civil society organizations often act independently of other actors. Even where competitive pressures provide strong incentives for partnership, collaboration does not develop.
- *Enabling environment:* Research and training support and financing mechanisms are in place but are poorly attuned to the emerging needs of the sector. Intellectual property rights protection may have become important to allow providers of new technologies to grow, but a property rights regime is not in place or cannot be enforced.

The Dynamic Phase: The ultimate phase of orchestrated and opportunity-driven systems is a dynamic system of innovation, which can be established with the right support. The sector is agile, neither publicly nor privately led, but instead characterized by public-private interactions, including collaboration in planning and implementation. It responds quickly to challenges and opportunities, and delivers economic growth in socially and environmentally sustainable ways.

- *Actors and roles:* Government, private, and civil society organizations all play important roles, determined by the nature of the sector and the challenges it faces, and have evolved over time. Research plays a prominent role through strong private sector demand for public research or through privately funded and/or operated research. Sector-coordinating bodies help identify and address technical and organizational issues, including research priorities, quality standards, sector brand image, and trade and policy negotiations. Financial organizations have developed financial products for the sector's specific needs.
- *Attitudes and practices.* There is openness to partnering, tradition of collaboration, trust between major actor groups, inclusiveness of poor actors, strong research culture in enterprises, and low risk-aversion. Business culture of social and environmental concerns.
- *Patterns of interaction:* A dense networks of interactions links the key actors, and may be contract based, project based, governance based, or informal. The network renews and adapts itself in response to new opportunities and challenges.
- *The enabling environment:* Sufficient resources are available for research and training, organized in ways that encourage interaction between organizations. Incentives exist for risk taking, and venture capital is available to promote innovation.

1.2 Diagnostic features for the AIS development phase

The diagnostic assessment of the data assesses the characteristics, context and capacity of the IS to reveal divergence between actors and their practices, as well as of changing demands:

Actors, roles they play, and activities in which they are involved:

- Are the active organizations from the public and private sector sufficiently diverse?
- Is the range of actors appropriate to the nature of the sector, the stage of development of the market, and the institutional setting of the particular country?

Attitudes and practices of the main actors:

- What attitudes enable or restrict collaboration between organizations?
- What ineffective or conservative behavior can be identified?
- Do patterns of trust and reciprocity exist to serve as foundations for evolving and future collaboration across the innovation system?
- Does a culture of innovation exist? Is there a demand for research in the private sector? Is there an emphasis on capacity building for future eventualities, or do organizations simply deal reactively with their present problems and opportunities? Is the use of collaborative arrangements for knowledge-based activities common? Is there an emphasis on both mastering new technology and accessing and using knowledge more effectively?

Patterns of interaction:

- Are there networks and partnerships between private companies, farmer organizations, NGOs, and research and policy organizations?

- Are the concerns of the poor integrated in the activities of the innovation systems, and are there mechanisms to promote their agenda?
- Are sector-coordinating bodies present or absent? If present, are they effective?
- Are stakeholder bodies, such as farmer and industry associations, present or absent? If they are present, what is the scope of their knowledge-based activities, such as research, training, technology acquisition, market and technology forecasting?

Enabling environment (policies and infrastructure):

Are there science and technology policies to promote collaboration (such as competitive grant funds for partnerships), to scale up innovations (such as incubators or venture capital), or to encourage private research investments (such as matching grants)?

Do fiscal policies promote research and development? Are farmer and other organizations involved in defining research and innovation challenges?

Do legal frameworks exist to facilitate the application of new (international) knowledge?

2.1 Principles for intervention

Initiating interventions (that build trust or improve the ability to scan and reduce risk for new opportunities) allow the transition from the pre-planned phase to the foundation phase.

Experimental interventions (for example, that support partnerships on emerging opportunities or develop attitudes, practices, and financial incentives) allow the transition from the foundation phase to the expansion phase.

Interventions that help build on or nurture success (for example, that expand proven initiatives, strengthen good practices, and address weaknesses) allow the transition from the expansion or emergence phase to a dynamic system of innovation.

Remedial interventions (for example, that build coherence and links between the research system and the sector, support coordination bodies, and strengthen or redesign existing organizations) help resolve the weaknesses of innovation capacity in the stagnation phase.

Maintenance interventions (for example, that maintain agility and the ability to identify new opportunities and challenges, enhance collaboration across actors and sectors, and contribute to the maintenance of an enabling environment) help ensure that dynamic systems of innovation do not deteriorate.

2.1 Options for intervention

Pre-planned phase in the orchestrated trajectory

Intervention principles: Interventions should improve the awareness and ability of the existing actors to look for new opportunities, as well as help build trust between the different players. With a potentially large number of different opportunities to choose from, many of which will turn out to be inappropriate, another useful intervention principle is to establish measures to reduce the risk of pursuing new opportunities. Options include:

- Establish a joint foresight group of industry, government, civil society, and research community representatives to review and address threats and opportunities for agriculture.
- Establish management mechanisms for research and training that allow agribusiness to participate in strategy development, priority setting, and funding.
- Provide incentives for the private sector to invest in agro-industrial activities in rural areas in partnership with research organizations.
- Establish mechanisms to reduce risks to new entrepreneurial activity, such as tax incentives, grants, or new financing mechanisms.

Foundation Phase in the orchestrated trajectory

Intervention principles: The key principle is to get different actors to work together on specific opportunities and projects identified by the main actors. Interventions should focus on addressing emerging opportunities (existing or new), building trust among the actors, and developing the attitudes and practices as well as financial incentives needed to promote interaction between key players in the sector. Options include:

- Provide consortia-based research funding to encourage basic public-private interactions.
- Pilot business models based on small-scale producer networks.
- Provide incentives for collaboration with foreign agroprocessing companies to expose the sector to different business cultures.
- Provide incentives for the private sector to invest in agro-industrial activity in rural areas in partnership with research organizations.
- Create farmer associations to help so farmers can become more effective business partners and acquire knowledge and technology.
- Create or strengthen intermediary organizations that can broker and facilitate linkages between poor producers, private enterprises, and research organizations.
- Create venture capital funds for rural innovation.

Expansion phase in the orchestrated trajectory

Intervention principles: Interventions should focus on identifying and further expanding the mechanisms and initiatives that have proved to work. For example, if funding for research and industry consortia has been effective, this mechanism may be expanded to new themes or commodities. Interventions should also strengthen existing good practices and address emerging weaknesses in current mechanisms. Options for intervention include the following:

- Revitalize NGO networks, with a focus on learning and capacity building.
- Expand consortia-based research funding for topics where interaction between private companies and research organizations is important.
- Provide matching grants to support private sector investments in research.
- Create or strengthen a sector-coordinating body with members from the public sector, private sector, and NGOs and representatives from major markets.
- Establish training and research facilities jointly sponsored and governed by the public and private sector, perhaps including postgraduate programs.
- Change university curricula and involve the private sector in university governance.
- Establish internships / exchange with industry, universities, and coordinating org's.
- Establish mechanisms for quality and trade certification, and create advisory capacity for achieving compliance.

Nascent phase in the opportunity-driven trajectory

There are no principles or options for the nascent development phase because the need for intervention is not apparent until some opportunities show potential in the emergence phase.

Emergence phase in the opportunity-driven trajectory

Intervention principles: Interventions should help the public and private actors address their challenges in a collaborative manner, by means of developing coordination mechanisms and incentives to encourage collaborative attitudes and practices in research, training, standards and grades, and brand development. Interventions should support select clusters of activities, which will help further innovation towards both economic and social goals. Options include:

- Provide consortia-research funding for public–private interactions in emerging sectors.
- Establish business models based on small-scale producer networks.
- Create farmer associations so farmers can become more effective business partners and acquire knowledge and technology.
- Create venture capital funds for rural innovation.
- Create or strengthen a sector-coordinating body with members from the public sector, private sector, and NGOs and representatives from major markets.
- Establish training and research facilities jointly sponsored and governed by the public and private sector, perhaps including postgraduate programs.
- Change university curricula and involve the private sector in university governance.
- Create internship, exchange programs with industry, universities, coordinating orgs'.
- Establish advisory capacity for achieving compliance with quality and trade certifications.
- Launch product brands based on small-scale processing.
- Establish policy dialogues with public and private sector, NGOs, research participation.
- Establish a sector-specific research fund governed by sector representatives.
- Strengthen NGOs to become intermediary organizations that nurture rural microenterprises, with a focus on knowledge sharing and business skills.

Stagnation phase in the opportunity-driven trajectory

Intervention principles: At this stage the sector's economic importance has become clear and the dimensions of future efforts can be defined, and thus interventions that are able to link the research system and the sector are important. Coherent action among actors as well as donors, is needed to address the various emerging technical, environmental, social, and market issues. Sector-coordinating bodies allow different actors to share positions and agree on the main issues for development will play an important role. Attitudes of non-collaboration also encourage a step-by-step approach of specific issues and tasks to slowly build up collaboration, thus it is important to strengthen existing organizations to promote stronger interaction patterns or redesigning research, training, or education programs to become more agile. Options include:

- Provide consortia-research funding for public–private interaction in emerging sectors.
- Establish business models based on small-scale producer networks.
- Provide incentives for collaboration with foreign agroprocessing companies to expose the sector to different business cultures.
- Provide incentives for the private sector to invest in agro-industrial activity in rural areas in partnerships with research organizations.

- Create farmer associations so farmers can become more effective business partners and acquire knowledge and technology.
- Create or strengthen intermediary organizations that can broker and facilitate linkages between poor producers, private enterprises, and research organizations.
- Create venture capital funds for rural innovation.
- Create or strengthen a sector-coordinating body with members from the public sector, private sector, and NGOs and representatives from major markets.
- Establish training and research facilities jointly sponsored and governed by the public and private sector, perhaps including postgraduate programs.
- Change university curricula and involve the private sector in university governance.
- Establish internship, exchange programs with industry, universities, coordinating orgs'.
- Establish advisory capacity for achieving compliance with quality and trade certifications.
- Launch product brands based on small-scale processing.
- Establish policy dialogues with public sector, private sector, NGO, research participation.
- Establish a sector-specific research fund governed by sector representatives.
- Strengthen NGOs to become intermediary organizations that nurture rural microenterprises, with a focus on knowledge sharing and business skills.
- Locate research organizations and enterprises (agribusiness science parks) on campuses.

A dynamic system of innovation

Intervention principles: Interventions should focus on maintaining the IS's health and agility to remain well connected to the evolving context, with attitudes and practices needing to remain open-minded and collaborative: the system's enabling environment stays in place, or may bring up new activities requiring new types of research support or organizations. Options include:

- Establish a joint foresight group of industry, government, civil society, and research community representatives to review and address threats and opportunities for agriculture.
- Locate research organizations and enterprises on the same campus for collaboration.
- Conduct detailed surveys to track sector innovation; conduct knowledge-sharing events.
- Develop novel research, training, or financing organizations to pursue new opportunities.
- Conduct trade fairs to bring private and public innovation options together.