Inclusive Value Chain Development:

Applying Systems Thinking and Participatory Modeling to Dairy Value Chain Analyses in Nicaragua and Tanzania

Inkluderende verdikjedeutvikling:

Bruk av systemtenkning og deltagende modellering i analyse av melkeverdikjeder i Nicaragua og Tanzania

Philosophiae Doctor (PhD) Thesis

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Summary

This thesis explores how policy-makers and other stakeholders can support smallholder participation in higher-value marketing chains despite the many challenges faced by smallholders in developing countries. The overall aim is to provide decision support tools that contribute to improving smallholder livelihoods through inclusive value chain development. This is accomplished by applying systems thinking and modeling to value chain analysis in order to provide deeper context-specific understanding of the complex and dynamic systems present in value chains, and to be able to better test the implications of value chain policies and interventions. Two case studies, the dairy value chain in Mgeta, Tanzania and the dairy value chain in Matiguás, Nicaragua, were chosen for this research because livestock represents a potential pathway out of poverty for many smallholders, while at the same time representing complex and dynamic value chains.

The thesis comprises four separate but interrelated articles that, in different ways, explore, test, and develop the use of systems thinking and participatory modeling in value chain analysis. These articles investigate important aspects of smallholder inclusion in value chain development such as challenges with partnerships, the complexities of value chain governance, the potential of participatory modeling in decision-making, identification of dynamic processes present in smallholder dairy value chains, and the possibilities of testing intended and unintended consequences of different value chain policies and interventions over different time scales. This is accomplished by using mixed methods approaches, constructing causal loop diagrams and stock and flow diagrams, and by applying a participatory modeling approach.

The research illustrates and confirms various opportunities and challenges which smallholders face when participating in or entering into higher-value marketing chains. The thesis concludes that a systems thinking and participatory modeling approach to inclusive value chain development can provide valuable decision-making tools to policy-makers, and to others intervening in value chains. These tools can help in prioritizing which policies and interventions have the potential to strengthen smallholder competitiveness and inclusion in value chains, and can increase smallholder income over time. The thesis provides valuable empirical case-specific findings, as well as important conceptual and methodological developments applicable to a variety of developing country settings.

Sammendrag

Småbønder i utviklingsland har mange utfordringer. Denne oppgaven utforsker hvordan beslutningstakere og andre aktører kan støtte småbønders deltakelse i verdikjeder (fra produsent av mat til forbruker). Det overordnede målet er å utvikle verktøy som kan bidra til beslutninger som kan bedre småbønders levebrød gjennom inkluderende verdikjedeutvikling. Dette oppnås ved å anvende systemtenkning og modellering i verdikjedeanalyse for å gi en bedre forståelse av de komplekse og dynamiske systemene som finnes i verdikjeder, og for å kunne teste konsekvensene av ulike verdikjedestrategier og -intervensjoner. To case studier, melkeverdikjeden i Mgeta, Tanzania og melkeverdikjeden i Matiguás, Nicaragua, ble valgt for denne forskningen fordi husdyrhold er en potensiell vei ut av fattigdom for mange småbønder, samtidig som det inngår i komplekse og dynamiske verdikjeder.

Avhandlingen består av fire separate artikler som er relatert til hverandre, og som på ulike måter utforsker, tester, og utvikler bruk av systemtenkning og deltakende modellering i verdikjedeanalyse. Artiklene utreder viktige aspekter for inkludering av småbønder i verdikjeder. De beskriver utfordringer knyttet til partnerskap og koordinering av verdikjeden, potensialet for deltakende modellering i beslutningsprosesser og identifisering av dynamiske prosesser i småbønders verdikjeder. I artiklene vurderes også mulighetene for testing av tilsiktede og utilsiktede konsekvenser av ulike verdikjedestrategier og -intervensjoner over ulike tidsperspektiver. Dette oppnås ved å bruke flere metodiske tilnærminger som årsak-virkning diagrammer og «stock and flow» diagrammer, og ved å anvende deltagende modellering.

Forskningen illustrerer og bekrefter ulike muligheter og utfordringer småbønder møter når de deltar i, eller forsøker å delta i, verdikjeder. Avhandlingen konkluderer med at å bruke systemtenkning og deltakende modellering i inkluderende verdikjedeutvikling kan gi verdifulle verktøy for beslutningstakere og andre som arbeider med å støtte småbønders deltagelse i verdikjeder. Disse verktøyene kan bidra til å prioritere de strategier og tiltak som har høyest potensial til å bedre småbønders konkurranseevne og øke deres inntekt over tid. Avhandlingen gir verdifulle empiriske case-spesifikke funn, samt bidrar til utvikling av teori og metode som kan anvendes i ulike sektorer i utviklingsland.

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AA	Accidental Adversaries
CATIE	Tropical Agricultural Research and Higher Education Center
CIAT	International Center for Tropical Agriculture
CFS	Committee on World Food Security
CLD	Causal loop diagram
FAO	Food and Agriculture Organization of the United Nations
GCC	Global commodity chain
GDP	Gross domestic product
GMB	Group model building
GIZ	German development agency
HLPE	High Level Panel of Experts on Food Security and Nutrition
IDS	Institute of Development Studies
IIED	International Institute for Environment and Development
IFAD	International Fund for Agricultural Development
ILO	International Labour Organization
INIDE	Instituto Nacional de Información de Desarrollo
MAGFOR	Ministerio Agropecuario y Forestal (Ministry of Agriculture and Forestry)
M4P	Making Markets Work for the Poor
Nitlapan	Instituto de Investigación y Desarrollo (Institute for Research and Development)
NMBU	Norwegian University of Life Sciences
NRC	Norwegian Research Council
NGO	Non-governmental organization
SNV	Netherlands Development Organisation
SUA	Sokoine University of Agriculture
SD	System Dynamics
SFD	Stock and flow diagram
UNIDO	United Nations Industrial Development Organization
VCA	Value Chain Analysis

PART ONE: Introduction Chapter

1. INTRODUCTION

1.1 Context and background

Transformation and the increasing dynamism of agri-food systems offer opportunities, as well as pose challenges, for integration of smallholder farmers into remunerative local, regional, and global markets. The demand for higher-value agricultural products is growing, in both developing countries and foreign markets, as the result of urbanization and exit from agriculture. There is an increasing concentration of populations in towns and cities who are, on average, becoming richer, which leads to changing food preferences (Arias et al. 2013; IFPRI 2017). The demand for meat, dairy products, and high quality and specialty vegetables is growing. There is also increasing demand for processed products and niche market products such as organic or fair trade products (Devaux et al. 2016). Connecting the world's two billion smallholders who provide about 70% of overall food production in the world to such markets, whether local or global, is a potential pathway for reducing rural poverty and inequality. Smallholders constitute 75% of the rural poor (CFS 2015). Inclusion, in addition to better conditions for participation in value chains, provides smallholders with options to improve their livelihoods and contribute to overall food security in developing countries. However, this requires a focus on both economic as well as social goals in value chain development (IFPRI 2017). There is a concern that those who depend on smallholder agriculture for their livelihoods have difficulties in accessing markets and participating in higher-value marketing chains, and do not benefit from these opportunities (Silva & Rooyen 2016).

Most smallholder farmers, and particularly poor rural farmers, face numerous challenges in accessing markets. The value chains of commercial markets are highly competitive and specialized, with high quality standards, large demand quantities, and timely deliveries, which are challenging for smallholder farmers (CFS 2015; Devaux et al. 2016). The barriers that smallholders face in participating in value chains and accessing markets vary from physical barriers (poor infrastructure), human barriers (poor education), and social barriers (limited coordination of farmers), to limited access to training, information and means of communication. Limited access to finance is also often challenging. Likewise are production-related barriers such as access to inputs and agricultural technology leading to poor product quality and low quantity. Cultural aspects and traditional ways of trade and consumption also influence market development (Arias et al. 2013). Consequently, only 2% to 10% of smallholders are able to access formal value chains (Vorley et al. 2012).

As a result of these challenges, many smallholder farmers have limited contact with commercial markets and hence a poor understanding of, and ability to, react to market forces. This can lead to their exclusion and marginalization. Value chains and markets are highly context-specific; examining which value chains to target and under what conditions smallholder farmers participate, is critical. It is challenging to compete with large firms that have the benefit of economies of scale, closer connections with the consumer, strong brands, access to technology, and information to be innovative and meet changes in the markets. While it is possible that partnering with such firms can open opportunities, these should be embraced with caution to avoid exploitative relationships. Governance is therefore a critical element in value chain development.

Collective action is also an opportunity for upgrading, as well as developing products and brands for local or regional markets where smallholders have better opportunities to understand the market and to access information (Silva & Rooyen 2016). Increasing productivity among many smallholders can enable them to supply markets with diverse food products. Smallholders may also have a comparative advantage in producing high-value, labor-intensive products such as perishable fruits, vegetables, and specialty crops and other agricultural products (CFS 2015; Devaux et al. 2016). Hence, several strategies exist to increase smallholder competitiveness (ability to meet demand and requirements in the market) and participation in value chains. A stronger focus on understanding and developing inclusive value chains in developing countries is needed.

Inclusive value chain development specifically considers the participation of vulnerable social groups such as smallholders. Such groups could be further specified into groups such as women, youth, or those belonging to a marginalized ethnic or geographic group, whether they are smallholders or not (Helmsing & Vellema 2011b). Smallholders can participate in value chains as input-providers, producers, traders, processors, and retailers, as well as consumers. Thus, inclusive value chain development – sometimes referred to as ‘pro-poor’ value chains (Altenburg 2006a; Seville et al. 2011; UNIDO 2011) – is closely linked to employment-generation, economic growth, and food and nutrition security. Inclusive value chain development does not necessarily focus on export, but can focus on including smallholders in local, national, or regional markets. The goal is to reduce the barriers to entry in value chains and allow for more diverse value chains (M4P 2008; UNIDO 2011).

Smallholders are a heterogeneous group with respect to land availability and to amount and type of resources they have available. Their livelihood strategy is often diversified and consists of both on-farm and off-farm work. There is no universal definition of smallholder farmers because smallholder agriculture includes crop farming, livestock, forestry, fisheries, pastoral and aquaculture production. They are often largely reliant on family labor and have limited access to assets. It is common to classify small farms based on the land size they operate. However, this is context-specific based on land type, the sector they operate in, and historic and current economic, social, and technological conditions. National definitions in terms of land size or number of animals is more accurate than the commonly used definition of operating less than two hectares of land (Arias et al. 2013; CFS 2015; HLPE 2013). In this thesis, national definitions of smallholders and small-, medium-, and large-scale farmers are used, which are provided in the introduction to the study areas.

For many smallholders in low-income countries, livestock systems represent a potential pathway out of poverty (Herrero et al. 2013). Globally, livestock play a vital role in ensuring a diverse diet, with milk being an important aspect of this. Worldwide, 150 million households, the majority being smallholder farmers in low-income countries, depend on milk production for their livelihoods (FAO 2013). Milk offers a regular income since it is produced and sold daily, with small-scale dairying generating employment in milk collection, processing, and marketing. The demand for milk and dairy products is increasing because of population growth, but also because of greater per capita consumption of milk and dairy products than before (Dugdill et al. 2013; Tschirley et al. 2014). Cattle and dairy production and markets are also complicated due to climate and infrastructure challenges that complicate access to markets (Herrero et al. 2013).

In Tanzania and Nicaragua, the locations for the two case studies analyzed in this thesis, keeping of livestock is a large part of the economy, in which the majority are smallholder livestock producers. In Tanzania, about 40% of the almost five million agricultural households depend on livestock as a source of income. Dairy accounts for 30% of national livestock gross domestic product (GDP), but only about 10% of the approximately 4.5 million liters of milk produced per day (in 2007) reaches formal markets. Hence, there are significant opportunities for upgrading the dairy value chain (Njombe & Msanga 2011; URT 2012). In Nicaragua, livestock contributes 45% to the national agricultural GDP. There has been an increase in milk production over the past five years, amounting to about 2 million to 2.3 million liters produced per day, of which between 40% to 50% reaches formal processing plants (in 2011) (Holmann 2014; MAGFOR 2013). The dairy sector in Nicaragua is also smallholder producer-based, and with the rapid commercialization of the dairy sector, inclusion of small- and medium-scale producers is an important policy issue. A large difference between the two countries is that Nicaragua exports milk (MAGFOR 2013), while Tanzania largely relies on milk imports (Njombe et al. 2011). However, both countries have a large informal dairy sector.

Understanding the complexity and dynamics of dairy value chain systems is central to realizing the potential of the dairy sector in Tanzania and Nicaragua, and to support smallholders in taking advantage of the opportunities that exist in higher-value agricultural chains. Value chain complexity derives from the interaction of many actors and nodes that include upstream and downstream flow of information, capital, and materials. Social, economic, political, and environmental aspects have impacts in all parts of the chain. Agricultural value chains are also driven by seasonality, as well as delays in information and decision-making. Cause and effect can also be distant in time and space, making it difficult to anticipate impacts beforehand. This thesis provides a deeper understanding of the dynamics encapsulated within selected dairy value chains in Nicaragua and Tanzania, and assesses the possibilities for strengthening smallholder inclusion.

1.2 Status of knowledge

Value chain analysis (VCA) has become an increasingly popular framework among development and research institutions (Gereffi 2014; Humphrey & Navas-Alemán 2010). VCA provides a useful framework to analyze the complex agricultural systems from inputs and production, to processing, distribution, sales, and even disposal after use (Kaplinsky & Morris 2001). A number of value chain frameworks have been developed to guide practitioners and researchers on the analysis and development of inclusive value chains (e.g. GIZ 2008; M4P 2008; Riisgaard et al. 2008; World Vision 2016). Several of these frameworks focus specifically on enhancing smallholder farmer livelihoods, and more specifically on smallholder women (Agri-ProFocus 2012; Mayoux & Mackie 2007;

Terrillon & Smet 2011). The benefit of VCA is that it can be conducted from the perspective of any participant in the chain. The structure of VCA starts with mapping, identification of governance structures, upgrading opportunities, and distribution of benefits. It provides a framework for actors in the value chain, as well as researchers and development practitioners with different backgrounds, to work together to improve smallholders livelihoods through inclusive and sustainable value chains.

Value chain analysis is an interdisciplinary approach with economic, social, natural, institutional, and environmental aspects. Knowledge of production and processing, as well as an understanding of the role of marketing, economics, the environment, and gender, are among the important elements in successful value chain development. Focusing on the value chain, instead of on a specific sector or commodity, enables the analyst to address the system the smallholders participate in, and identify the role that contextual factors such as governance play in determining market access (Rich et al. 2011).

The in-depth contextual background can be used to identify bottlenecks and opportunities for upgrading with associated interventions. However, VCA is mostly qualitative and descriptive and it is therefore difficult to test or understand *ex-ante* the plausible impacts or outcomes that different interventions might have on these complex systems. An intervention will have both upstream and downstream effects, meaning that it can affect both the production and marketing features of the chain. These effects can be intended and unintended, and positive as well as negative, which can reduce the effectiveness of a specific intervention over time. Therefore, it is important to identify and use analytical frameworks that can provide a richer understanding of the impacts that different interventions and policies could have on the value chain and its participants.

Systems thinking and system dynamics (SD) methods are means to address these gaps in traditional VCA. Systems thinking and modeling is a methodology for understanding the relationship between the structure of a complex system, such as a value chain, and its dynamic behavior over time (Sterman 2000). An SD model maps the material and information flows, processes, decision rules, relationships, and feedback effects that exist between actors operating within a complex system, such as a value chain. The methodology is interdisciplinary and can be used as a tool to test and analyze interventions and policies, as well as areas of potential policy resistance (Sterman 2000). Recent research on value chains has revealed the utility of this approach in agricultural and livestock systems in *ex-ante* testing of the potential dynamic impacts of feedbacks from different policy and technical interventions within the chain (Naziri et al. 2015; Rich et al. 2011).

An advantage of SD models is that they can be conceived and developed through participatory processes, which is of particular importance when aiming for inclusive value chain development. Participatory SD modeling enables the inclusion of the value chain actors and its enabling environment in model construction, testing, and decision-making. It provides a shared language and group learning, and it builds consensus and commitment to chosen strategies (Rouwette & Vennix 2006). Participatory modeling is especially relevant when many stakeholders are involved and when many different intervention options (and potential conflicts among those options) exist. The ability to simulate the performance of the value chain based on different metrics of analysis enables stakeholders to better understand the possible consequences and trade-offs of a decision made within a complex system (Vennix 1996). Constructing simulation models requires in-depth and detailed information about value chains. Group model building (GMB) is also a helpful way of collecting data in development settings where data might be poor, outdated, or unavailable.

1.3 The objectives of the thesis

This thesis explores how policy-makers and others can support smallholder participation in higher-value agri-food chains despite the many challenges faced by smallholders in developing countries. The overall aim of this research is to provide decision support tools that contribute to improving smallholder livelihoods through inclusive value chain development. This is accomplished by applying systems thinking and participatory modeling to VCA in order to provide deeper context-specific understanding of the complex and dynamic systems present in value chains, and to be able to more effectively test the implications of value chain policies and interventions over different timescales.

To address the overall aim, four specific objectives and research questions have been identified. These are listed below. The first objective will be addressed using the case of the Mgeta dairy value chain in Tanzania; the three last objectives will be achieved using the Matiguás dairy value chain case in Nicaragua. Despite the use of two case studies, this research project is not a comparative study, but provides examples of applying systems thinking and modeling to inclusive VCA, and which contribute to similar issues found elsewhere in the developing world.

1. Advance the analytical framework of governance in value chains using a systems based approach to partnerships.
   - What role does governance play in developing and sustaining value chain partnerships?
   - How do new value chain partnerships affect the dynamics of value chain governance?
   - How do changes in value chain governance affect smallholder inclusion in value chains?

2. Demonstrate and assess how participatory SD modeling can be applied in the context of inclusive value chain development.
   - How can participatory modeling processes guide inclusive decision-making in value chain development?
   - What lessons for policy-making and value chain development can be obtained by the use of GMB in promoting dialogue in the dairy value chain in Matiguás?

3. Identify and explain the dynamic processes in dairy value chains.
   - What are the key actors and dynamic relationships in the Matiguás dairy value chain?
   - What are potential strategies and policies that can strengthen small- and medium-scale dairy farmers' competitiveness and inclusion in the Matiguás dairy value chain?

4. Assess the use of SD models to test and evaluate interventions and policies in agricultural value chains, and their possible implications for smallholder competitiveness and inclusion.
   - What are the short-, medium-, and long-term impacts of specific interventions and policies in the Matiguás dairy value chain?

1.4 Structure of the thesis

This thesis consist of two main parts: the introduction, and four academic articles. The main contribution is the four academic articles, which are provided in their entirety in the second section. The first section gives an introduction to the articles, by providing the background and the main theoretical frameworks on VCA and development, systems thinking, and SD modeling. Inclusive value chain development and the historical origins of VCA are presented, as well as the different phases of the analysis: mapping, governance, upgrading, and distribution of benefits, ending with highlighting the strengths and weaknesses of the framework. The theoretical framework also introduces key concepts such as systems thinking, SD modeling, and participatory model building.

The theoretical framework concludes by emphasizing how systems thinking and participatory modeling complement traditional VCA. This provides the starting point for presenting the design and implementation of this research project. The methodology covers the research design, an introduction to the study areas of Matiguás in Nicaragua and Mgeta in Tanzania, and the methods of data collection used throughout the research.

The section containing summaries of each article provides background to the conclusion of the thesis. The final section presents the overall empirical findings, as well as theoretical, conceptual, and methodological contributions, and policy implications. It also highlights some challenges and weaknesses of using systems thinking and modeling, and concludes by pointing towards future possibilities.

2. THEORETICAL AND CONCEPTUAL FRAMEWORK

This section introduces the two main theoretical frameworks used in this research: value chain development and analysis, and systems thinking and modeling. For each framework, important concepts, a brief history of the origins of the frameworks, and the analytical and methodological approaches are presented. Finally, the complementarity of the two frameworks which form the basis for this research, is highlighted.

2.1 Value chain analysis and development

2.1.1 Inclusive value chain development

A value chain represents the full range of activities that are required to create a finished product or service. This refers to the different phases of production from raw materials, processing, distribution, and marketing, until the product or service reaches the final consumer and is disposed of after use (Kaplinsky & Morris 2001). The value chain consists of actors who actively participate in the different nodes of the chain and who maintain dynamic relationships. It also involves the enabling environment, including policy-makers, service providers, and civil society, all of which impact on the value chain in different ways.

Value chain development can be seen as achieving positive or desirable changes in terms of improving competitiveness for a subset of chain actors, or establishing win-win relationships between chain actors (Donovan et al. 2015; UNIDO 2011). When focusing on inclusive value chain development, attention is also placed on achieving a desired development outcome. Examples of these outcomes are increased income, both in absolute and relative terms, in relation to other actors in the chain, as well as poverty reduction, employment generation, gender equity, food security, and enhanced use of locally produced raw materials (M4P 2008; UNIDO 2011). Inclusive value chain development is a fairly new concept, but it builds on and can also be referred to as pro-poor value chain development which has been actively used since the mid-2000s (Altenburg 2006a; Seville et al. 2011; UNIDO 2011). Inclusive value chain development facilitates participation of different social groups, such as smallholder farmers, and may further emphasize the role of caste, ethnicity, religion, and gender (Helmsing & Vellema 2011a; Hospes & Clancy 2011).

It should be noted that inclusion is not a dichotomy where value chain development outcomes result in smallholders being either “in” or “out”. Inclusion in value chains is a process that evolves over time (Hospes & Clancy 2011), and is affected by changes in seasonality, policies or the competitive landscape. Smallholders could be included in one chain but excluded in another. They can also be thoroughly incorporated into the chain, but marginalized in another sense (Bolwig et al. 2010). For example, they can participate fully in some activities such as production, but be excluded from other activities or nodes in the chain, such as processing. Inclusion is therefore not static, but a continuum and a process.

Inclusion is not necessarily good, nor is it bad. Some smallholders choose not to participate in value chains (Hospes & Clancy 2011). Because participation in a value chain increases smallholder risks, it is important to look at both the potential benefits and costs of participation (Bolwig et al. 2010). Smallholders could also stop participating in one value chain and move to another that offers better conditions. Hence, the conditions of participation are central when considering inclusion. Smallholders might be able to participate in a value chain, but according to terms that provide them with lower income and decision-making power (Helmsing & Vellema 2011a). Inclusiveness is therefore closely connected to how the value chain is coordinated, by whom, and how rules are made, implemented, and enforced. These issues are central to governance of the value chain (Kaplinsky & Morris 2001).

In the process of value chain development, there are four ways to look at changes in inclusion and exclusion of smallholder farmers (Bolwig et al. 2010). First, there can be an inclusion of new smallholders based on factors such as gender, age, and geography. Second, there can be a continued participation under new terms, for example when specific value chain interventions are implemented. Expulsion of participants is a third option, either self-excluded by switching to another activity, or through changes in the value chain which lead to exclusion. This could be caused by, for example, higher demands that lead to favoring larger producers at the expense of smallholder participation. Finally, it is important to point out that one cannot take it for granted that inclusion is always wanted by those who have been excluded. Continuing as non-participants for different reasons may also be desired by some (Bolwig et al. 2010).

Smallholders in value chain development need to participate in the process of desired inclusion (Vellema 2016). In inclusive value chain development, smallholders should be able to take part in decision-making concerning interventions that affect both their participation and terms of participation. Paying attention to the intended as well as unintended effects of value chain interventions is important, in order to avoid “adverse inclusion” where smallholders are included in a project, but it does not result in positive outcomes for them (Ros-Tonen et al. 2015). Interventions could increase or reproduce inequality despite fostering inclusion (Hospes & Clancy 2011). It is therefore of significant value to carry out a detailed analysis of value chains before taking a decision to intervene.

2.1.2 Historical origins of value chain analysis

VCA emerged from various intellectual streams including the French *filiére*, Michael Porter’s approach to value chains, supply chain management, world systems theory, and the global commodity chain approach, later known as the global value chain approach.

The French *filiére* (thread or chain) approach dates from the 1960s, and concentrates on optimizing physical flow of products within a sector, aiming for large-scale value addition and export. This approach was initially used to analyze French agriculture. It was soon applied in the analysis of agriculture in developing countries, focusing on improving the export of commodities such as coffee, cocoa, and cotton from the French colonies. It has its origin in technocratic agricultural research and focuses mainly on efficiency and extraction of resources by measuring inputs and outputs, prices, and value addition along the chain (Raikes et al. 2000).

Supply chain management from the business strategy literature emerged in the beginning of the 1980s as a multi-firm analysis of inventory management and logistics. It builds on the *filiére* approach, but deviates from the emphasis on nations and focuses on the logistics of optimizing flow of products and services between stages in the value-creating chain, to maximize supply chain profit. It is more than logistics, however, because it also considers issues such as finance, information, knowledge, and strategic collaboration. It was driven by technological development and industrialization (Bair 2009; Lambert & Cooper 2000).

The term “value chain” comes from the work of Michael Porter. Unlike the approaches discussed above, Porter’s (1980, 1985) value chain concept relates to firm-level strategy. His focus is on analyzing the relationships between different actors and activities within an organization. By managing these internal functions and relationships successfully, a business can secure value addition for its customers. Managers can further improve the firm’s competitive advantage through positioning it more advantageously in relation to their suppliers, buyers, and competitors. Porter uses “value chain” to describe the primary and support activities which make up the value-adding activities in a firm. The different value chains, or the firms themselves, are connected to each other in a system of value chains, often beyond national borders, which Porter refers to as “value systems”. and which are now often referred to as value chains (Porter 1985).

The global commodity chain (GCC) approach, introduced in the mid-1990s, combines an emphasis on value addition within firms or nodes in the value chain, with globalization. This is achieved by emphasizing the growing importance of global firms and how they coordinate activities across multiple countries (Gereffi & Korzeniewicz 1994). The approach builds on the world systems perspective, which highlighted the power of states and division of labor among countries in shaping global production systems. World systems theory was developed by Wallerstein in the late 1970s (Hopkins & Wallerstein 1977) and has its origins in dependency theory. In the GCC approach, the main focus is on industrial commodity chains where actors are connected to each other across space through world markets. Bair (2009: 9) refers to global commodity chains “as the infrastructure of international trade”. This was appealing to many development studies scholars who witness the increasing adoption of export-oriented industrialization strategies across the global South throughout the 1980s and 1990s and was looking for a way to analyze these policies and their consequences. The GCC approach provided macro and long range historical analysis of commodity chains, also on a comparative basis (e.g. see Gereffi & Wyman 1990). The most important contribution within GCC was the emphasis on governance relationships both between and within actors at each stage of a value chain. Commodity chains were classified as either buyer-driven or supplier-driven based on the lead firm in the chain (Gereffi & Korzeniewicz 1994).

The global commodity chain was later developed and re-named “global value chain” in the 2000s and focused more on the relative value created by the different actor in the chain (Bair 2009). The global value chain approach incorporates Porter’s focus on value addition and the supply chain management emphasis on optimizing the supply chain and apply it to a development context, acknowledging the importance of having a global perspective such as the *filiére* and world systems approaches. However, it is distinguished from the early focus on efficiency and extraction at the expense of the farmers. The global value chain approach further emphasized and developed value chain governance from the GCC approach (Gereffi et al. 2005). Value chain governance draws on transaction costs economics (Coase 1937; Stigler 1951) and is presented in more detail below.

2.1.3 Value chain analysis

Kaplinsky and Morris (2001) developed VCA as an analytical framework for practitioners based on the global value chain approach. Several non-governmental, international, and research organizations promote and conduct VCAs. Examples of these organizations are World Vision, CARE, and Netherlands Development Organisation SNV, the International Labor Organization (ILO), the Food and Agriculture Organization of the United Nations (FAO), the United Nations Industrial Development Organization (UNIDO), the International Fund for Agricultural Development (IFAD), the World Bank, the International Institute for Environment and Development *(*IIED) and the International Center for Tropical Agriculture (CIAT).

Value chain analysis, as implemented by practitioners, addresses market development in local, regional, and national value chains, especially with smallholder farmers as the target group (Herr 2007; M4P 2008; World Vision 2016). There are several VCA frameworks that have slightly different perspectives, but most have been based on the work of Kaplinsky and Morris (2001). Some frameworks focus specifically on pro-poor growth (GIZ 2008; M4P 2008), on smallholders (Lundy et al. 2014; Riisgaard et al. 2008), on gender (Agri-ProFocus 2012; Mayoux & Mackie 2007; Terrillon & Smet 2011), on local value chain promotion (World Vision 2016), or on participatory approaches (Lundy et al. 2014; Riisgaard et al. 2008).

Value chain analysis provides analysts and practitioners with a structured, yet flexible framework, to identify the flow of products and interactions between different actors in a value chain. It forces the analyst to consider micro, meso, and macro aspects of production and exchange activities. The analysis of a value chain therefore helps to identify strengths, weaknesses, opportunities, and constraints in the value chain, from an economic as well as an institutional standpoint. This analysis is the basis for developing value chain interventions.

Value chain analysis has four main components: (i) mapping the value chain, (ii) analyzing the governance structures of the chain, (iii) identification of opportunities for upgrading, and (iv) assessing distribution of benefits in the value chain. There are many case studies following the value chain framework. Dolan and Humphrey (2000) examined the changing governance patterns in the trade of fresh vegetables between Africa and the United Kingdom, while Dolan and Sutherland (2002) highlighted gender and labor conditions in Kenyan horticulture. In another study, Ponte and Ewert (2009) conducted a value chain analysis of South African wine, in terms of upgrading through improved product quality and associated processes.

Mapping the value chain identifies the flow of products, services, and information as well as the actors and the enabling environment, and the linkages between them. The goal is to understand the actors, relationships, and interconnections in order to identify entry points or key leverage points to improve the value chain performance. This provides a visual representation and overview of the actors and transaction patterns in the value chain (GIZ 2008; Lundy et al. 2014; M4P 2008).

Analyzing governance structures is a crucial step to understand the nature of relationships and the coordination mechanisms that exist between actors in the value chain. Value chain governance has been discussed and developed over the past 20 years (e.g. see Gereffi et al. 2005; Gereffi & Lee 2014; Gibbon et al. 2008; Humphrey & Schmitz 2001; Kaplinsky & Morris 2001; Ponte & Sturgeon 2014) and can be defined as "how certain actors set, measure, and enforce the parameters under which others in the chain operate" (Bolwig et al. 2010: 176). Governance examines how different decisions are made and implemented, how activities are coordinated, and how decision-makers are held accountable. The lead stakeholder in the value chain often has the power to control the terms of participation and thereby influence other actors' involvement. Socio-structural contexts such as power relations shape economic activity and are central when analyzing governance. The governance structure in value chains specifies what type of product is needed, by whom, how much, when and how it should be produced, and at what price. Governance includes power asymmetry, rule-making, sanctions, and degree of trust and dependence between the different parties (Bair 2009; Kaplinsky & Morris 2001).

Governance draws on transaction cost economics. This form of economics addresses the factors that determine when it is too costly to rely on market exchange and more efficient to internalize the exchanges within a firm (Coase 1937; Williamson 1979). Based on the complexities of transactions, governance can be categorized from open market coordination to hierarchies. In a similar manner, Gereffi et al. (2005) elaborate on the earlier literature of transaction cost economics from a sociological perspective, developing an expanded typology based on capabilities of the supply-base, complexity of transactions, and ability to codify transactions. The typology ranges from i) classic markets, with fairly simple products where price is the driving factor in an open market, to ii) modular value chains where suppliers with high capability more or less independently produce complex products for buyers, to iii) relational value chain governance with complex products requiring close interactions between buyers and sellers leading to mutual dependence and high level of asset specificity, to iv) captive form of governance where suppliers with limited capability are highly dependent on larger buyers. The last type, v) hierarchical governance, is characterized by vertical integration which is common when products and transactions are so complex that producing them in-house is the best solution. The degree of explicit coordination and power symmetry ranges from low in classical markets to high in hierarchies (Gereffi et al. 2005). When developing complex agricultural value chains, paying attention to coordination and lowering transaction costs is central to achieve competitiveness. Hence, governance is closely linked with upgrading, and sets the conditions for where and how upgrading can take place, as well as the implications of the interventions.

Identification of opportunities for upgrading – also referred to as strategies for adding value – is the intervention step of VCA. There are many different definitions of upgrading a value chain. Pietrobelli and Saliola (2008: 5) state that upgrading is "innovating to increase value added". Kaplinsky and Morris (2001), on the other hand, emphasize the importance of seeing upgrading in a wider perspective and as being distinct from innovation. Another definition is offered by Mitchell et al. (2009: 8) which defines upgrading as the "means [of] acquiring the technological, institutional and market capabilities that allow our target group (resource-poor rural communities) to improve their competitiveness and move into higher-value activities," which is a specific definition focusing on the human aspect of value chain upgrading. In this paper, the definition that will be used is offered by Riisgaard et al. (2008: 7): "Upgrading can be defined broadly as a positive or desirable change in chain participation that enhances rewards and/or reduces the exposure to risks". This is accomplished by identifying high leverage points for change in the value chain.

There are numerous approaches to upgrading a value chain. Kaplinsky and Morris (2001) identify four types which are often discussed in the value chain literature, namely process upgrading, product upgrading, functional upgrading, and chain upgrading. Process upgrading focuses on improving the efficiency of internal and external processes within individual nodes and/or between nodes in the value chain. Examples of this are processes that ensure timely deliveries, collection of quality produce, or improved marketing of a product (Kaplinsky & Morris 2001). Organizational restructuring, collaborations, or capability building are ways to achieve process upgrading. Product upgrading refers to improving existing products and/or developing new ones. Product upgrading is closely linked to process upgrading, because changes in products often lead to changes in processes. Functional upgrading is achieved when a firm changes one's position within the chain to add value. An example of this can be farmers who start processing in addition to producing vegetables. Finally, chain upgrading involves moving to a new chain altogether. If it turns out that participating in one chain is not profitable, farmers may look for other options. Smallholders often have a diversified livelihoods strategy and they might refocus from one crop to another, for example. But high barriers of entry into new value chains might limit their options (Kaplinsky & Morris 2001; Mitchell et al. 2009).

Assessing the distribution of benefits is the last step in VCA. This focuses on who gains and who loses in value chains. One approach is to observe who can participate, and the terms of participation, in terms of inclusive value chain development. Noticing where there is an increase in income is a common way of assessing benefits. Another approach is to calculate how added value is distributed among chain participants to address how much of the value goes to the smallholders versus the traders or the processors (GIZ 2008; Kaplinsky & Morris 2001). More secure market linkages and access to new services are also potential benefits from value chain interventions. Benefits in the value chain can be assessed when conducting the initial VCA, or after implementing upgrading strategies. However, assessing the impacts of value chain interventions can be challenging, owing to the complexities of value chain activities and relations which are constantly changing –even without any targeted value chain intervention (Humphrey & Navas-Alemán 2010).

2.1.4 Strengths and weaknesses of value chain analysis

VCA is a systematic analytical framework that goes beyond firm-specific and activity-specific analyses. It is a broad and flexible methodology which provides a context that helps to understand the complexities around flow of products, services and information, the business environment, relations, and decision-making in the value chain. This understanding supports design and implementation of value chain interventions that can support smallholder participation (Rich et al. 2011). The emphasis on governance is especially central to understand the reasons for inclusion and exclusion of smallholders (Altenburg 2006b). VCA enables analysts to take the point of view of any of the actors in the chain, such as smallholders (M4P 2008).

VCA is an interdisciplinary approach with economic, social, natural, and sometimes environmental aspects. It moves beyond the common emphasis of agricultural research and development projects on technological innovation at farm level. These studies often leave out important effects and links with processing and marketing at farm or local level (Devaux et al. 2016). The interdisciplinary approach strengthens the likelihood for achieving commercial viability, while at the same time resulting in social benefits. The analysis is based on fieldwork and primary data collection with key stakeholders. A multi-method approach is often used by combining primary surveys, focus group discussions, semi-structured interviews, and secondary data sourcing. The analysis can also be conducted in a participatory manner (e.g see Lundy et al. 2014; Riisgaard et al. 2008), which is important for smallholder agency.

On the other hand, VCA is time-, place-, and commodity-specific, and may leave out important dynamic effects and system-related aspects. It provides a picture of the value chain but does not effectively capture the changes that happen over time, whether it is within a season or over an extended period of years. This is problematic when considering the long-term effects of interventions. Economies and systems may change rapidly; a snapshot of today may be irrelevant three years from now. A value chain intervention can also have both positive and negative effects that are often not recognized or analyzed. An intervention in a specific node of the value chain can have effects on production, governance, economic, and/or marketing-related aspects, which will affect various actors differently. When aiming for inclusive value chain development, these are critical aspects to assess.

VCA is mostly based on qualitative analyses, apart from calculating profitability, the value added, and distribution of value. The analysis often identifies several opportunities for upgrading in different places in the value chain, but it does not offer a way of empirically measuring the performance of different intervention options along a host of criteria (economic, equity, environmental, inclusiveness). This requires a more detailed micro-analysis of the economic, production, and marketing systems and how they are linked and affected by decisions made at nodal level (Rich et al. 2011).

2.2 Systems thinking and modeling

2.2.1 Systems thinking and system dynamics

Systems thinking is a methodology that examines and recognizes the linkages and interconnections between elements that compose an entire system. Kim (1999: 2) defines a system as "any group of interacting, interrelated, or interdependent parts that form a complex and unified whole that has a specific purpose". Typical examples of systems are the human body, schools, businesses, social institutions, communities and national economies, forests, and agricultural value chains. A central tenant of systems thinking is that system structure drives system behavior; it is an endogenous perspective on behavior (Richardson 2011). An important objective of applying systems thinking is to identify high leverage intervention points in the system for sustained improvement and to avoid adverse reactions (Meadows 1997; Richmond 1994; Sterman 2002). Typical undesirable reactions include policy resistance, unintended consequences, and counter-intuitive behaviors (Forrester 1971a). Systems thinking can be seen as a language to understand model complex systems (Richmond 1994). SD is a simulation-based approach for policy analysis and design in complex dynamic systems.

SD was developed by Jay W. Forrester and his colleagues at the Massachusetts Institute of Technology (MIT) in the 1950s. It was initially developed and applied to engineering and industrial systems (Forrester 1961). The approach was further developed and later applied to understanding the dynamics of urban systems (Forrester 1970) and world systems (Forrester 1971b). The approach is now used in a wide range of disciplines such as economics, public policy, environmental studies, and management. Saeed (1994) applies systems thinking to development policy by looking at the dynamics of developmental processes such as, but not limited to, economic growth and income distribution, and food security. He argues that an SD approach is appropriate for dealing with developmental problems since it seeks to understand the causes in terms of the interactions of the system elements, rather than looking only at the symptoms of a problem. This perspective will lead to more sustainable solutions to development problems. Problems in developing countries are complex and can be seen from many perspectives. It is important to understand the system and its relationships before choosing an intervention (Saeed 1994). SD is an appropriate methodology to use when the problem identified is dynamic and complex, when the problem is chronic, and where many people have attempted to solve it without being successful. It is also suitable when various stakeholders find it difficult to align their efforts despite shared intentions, as well as when they try to optimize their part of the system without understanding their impact on the whole system (Stroh 2015).

Forrester (1971a) pointed out some time ago that policy-makers often make the wrong decisions owing to a limited understanding of complex and highly interacting systems. Sterman (2002: 1) even claims that "we are not only failing to solve persistent problems we face, but we are in fact causing them." Decision-makers tend to adopt a linear, event-oriented way of thinking where decisions are based on observed events and results (Sterman 1994; Sterman 2000). The unintended side effects of well-intentioned actions are often not considered, leading to dysfunctions in the system (Forrester 1971a).

One uses socially constructed mental models to understand one's surroundings, as well as to consider problems one is facing, which is in accordance with the social constructivist approach (Werhane 2008). A mental model is a thought process about how something works in the real world, which helps when dealing with experiences. It is based on assumptions about consequences of actions, and is used in everyday life to make decisions (Werhane 2008). Mental models are used by individuals but they also function at an organizational and systemic level (Senge et al. 1994).

One of the goals of systems thinking is to expand mental models so that one sees the patterns of behavior created by an underlying feedback structure, and not only the recent events (Sterman 2002). This enables one to understand the interdependencies in the system and to recognize the ramifications and trade-offs of different actions, often referred to as "feedback thinking", as oppose to a linear way of thinking. Feedback is defined as "the process wherein one component of the system initiates changes in other components, and those modifications lead to further changes in the component that set the process in motion" (McGarvey & Hannon 2004: 6). Feedback thinking enables decision-makers to see the big picture, strengthen commitment to long-term thinking and solutions, reduces the focus on quick fixes, and increases people's motivation to change (Stroh 2015). To expand the mental models and to fully understand complex systems, people need to cross disciplinary boundaries (Sterman 2002) and avoid a reductionist approach (Voinov & Bousquet 2010). Systems thinking can therefore be used to facilitate interdisciplinary cooperation. The unique vocabulary for describing systemic behavior – such as feedback, delays, and leverage points – makes it easier for different actors to communicate (Senge et al. 1994).

Critical realism, as opposed to a positivist or reductionist approach, can provide a philosophical underpinning for systems thinking; at the same time, systems thinking and concepts lie at the heart of critical realism (Mingers 2014). Critical realism is a combination of ontological realism and epistemological constructivism (Maxwell 2013). Critical realism goes back to Roy Bhaskar and gained prominence in the late 1970s and 1980s (see e.g Bhaskar 1978; 1986). Critical realists believe that phenomena and social reality occur in complex social-ecological systems that are generated by a multiplicity of invisible but powerful causal structures and mechanisms. These mechanisms are not directly observable, but their effects are apparent and can be collected and analyzed to explain events (Bhaskar 2010; Bryman 2008). In this way, they are similar to systems thinking. This often requires analysis of different parts and types of causal components of an open system, which requires an interdisciplinary approach. Practical and theoretical work of the social sciences, such as systems thinking and modeling, can be used to achieve this. The overall ontological and epistemological framework of this thesis is therefore inspired by critical realism.

2.2.2 Tools of systems thinking and modeling

Systems thinking is applied using a variety of methods, from informal maps to formal models with computer simulations, often referred to as SD modeling.

The most common ones are *causal loop diagrams (CLDs),* systems archetypes, and *stock and flow diagrams (SFDs)*. SD models and tools are used to visually portray the relations and feedback structures of a system, and if quantified can be used to conduct computer simulations that examine the impact of alternative scenarios over time (Richardson 2011; Senge et al. 1994; Sterman 2000). In systems thinking and SD modeling, there is, however, no single right answer as opposed to positivist paradigm. SD models identify a variety of potential actions, some that are high-leverage and some that are low-leverage. A leverage point is an area where a small change can yield large improvements in a system (Kim 1999). Each action will produce some desired changes and most likely some unintended consequences elsewhere in the system (Senge et al. 1994). This information can beneficially guide policy and decision-making.

A CLD is a qualitative map of a system that visualizes how different variables in a system are interrelated. CLDs are a good way in which to make mental models explicit. The CLD consists of multiple feedback loops that change the state of the system when decisions are made. Feedback structures can consist of physical relations such as the flow of products, or social relations such as attitudes or the ways decisions are made. Feedback relations can be positive and self-reinforcing, or negative and self-correcting. Reinforcing loops (R) strengthen the direction of the change resulting in continuous growth or decay. Negative feedback loops, often called "balancing feedback" loops (B), counteract change and result in stabilizing the process of growth or decay to some equilibrium (Sterman 2000). For example, a population of people or animals increases by number of births, which is a reinforcing feedback loop since the number of births increases the population, and when the population grows, the number of births simultaneously goes up. This positive cycle of growth is counteracted by number of deaths, a balancing feedback loop. A growing population increases the number of deaths, which reduces the size of the population. This example is illustrated using a simple CLD in Figure 1.

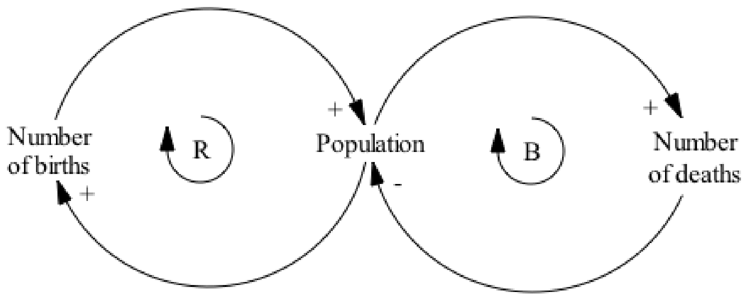

Figure 1: Causal loop diagram with a reinforcing and balancing feedback loop. Source: Modified from Sterman (2000: 138)

Archetypes are generic CLDs that have been developed to illustrate commonly seen behaviors in systems thinking. Archetypes can support those that are new to systems thinking and function as a starting point for developing more complex CLDs. Examples of archetypes are "Limits to Growth", "Tragedy of the Commons", and "Accidental Adversaries" (Senge et al. 1994; Wolstenholme 2003). The latter archetype is applied in Article 1 of this thesis.

SFDs present an operational specification of the system by using stocks, flows, and converters to capture the various feedbacks present in a system. Stocks characterize the state of the system, as well as anything that accumulates or drains over time. These could be physical such as a population or money, or intangible such as knowledge. Flows are decision variables in the system and represent material or information that enters or leaves the stock over a period of time. Inflows add to the stock and outflows drain the stock (Meadows & Wright 2008; Sterman 2000), for example, the number of births and deaths, or money that is earned and spent. A converter, also called a variable, influences one or several flows. It can be many different things, but always represents a relationship between something and the stock or the flow.

A simple SD model is illustrated in Figure 2, which is the stock and flow representation of the CLD of Figure 1. The total population, of people or animals, is a stock. The population increases by the inflow births. The number of births happening every year is determined by fertility, in Figure 2 named as "birth rate". The population is reduced by the outflow, deaths, which is influenced by mortality, here called "death rate". This makes up a balancing feedback loop, which counteracts with the reinforcing feedback loop of births. The dynamic interaction of these loops results in different forms of observed behavior over time. If the birth rate and the death rate are the same, there will be no changes to the total population. If fertility is higher than mortality, the population will increase, and vice versa. Delays are present in any system, and mean that the output, or outflow, lags behind the input. This could also be physical processes, such as the time it takes from a calf being conceived until

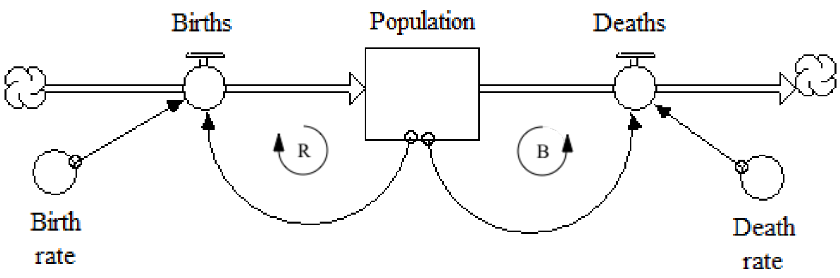

Figure 2: Example of simple stock and flow structure of a population
Source: Modified from Meadows and Wright (2008: 42)

birth, or the delay between planting and harvesting vegetables. An information delay arises if there is a delay between sending and receiving information (Sterman 2000).

Tools of systems thinking and modeling can be qualitative or quantitative. CLDs, including systems archetypes, are inherently qualitative. SFDs can be either qualitative or quantitative. The purpose of the analysis determines the type of model that is required (Vennix 1996). Qualitative SD models and associated tools highlight the structure of the system and the feedback relations, which provide insight into dynamic behaviors in the system. Qualitative SD models might be more accessible for various stakeholders without systems thinking experience, and can be useful when working with abstract concepts, such as power relations. CLDs can also be used as a way of summarizing and communicating SFDs. Quantitative SD models require more knowledge about modeling as well as data, which is not always available and can make the models speculative (Wolstenholme 1999). On the other hand, quantitative SD models enable simulation and testing of different scenarios over time. As a consequence of the different strengths and weaknesses of qualitative and quantitative SD models, it can be beneficial to use a mixed-methods approach, developing both a qualitative and quantitative model in a single project since they can easily and constructively build on each other (Wolstenholme 1999). Article 3 presents a qualitative SFD, which is further developed into a quantitative SD model in Article 4.

An important consideration is that models are not complete representations of reality, which means all models are inherently wrong. But some models are more useful than others in understanding reality (Sterman 2002), based on the quality of the thinking that went into creating the model (Richmond 1997), which relates to the model structure, data, and the process of model construction. Constructing models of high quality relies on a comprehensive understanding of the dynamic problem and associated system in focus, which requires involving the stakeholders of the system in model construction (Vennix 1996).

2.2.3 Participatory system dynamics modeling

Participatory modeling involves stakeholders in the process of developing a model. Stakeholders can be engaged in the form of knowledge provision, model selection and development, data collection, scenario development, interpretation of results, and development of policy alternatives (Voinov & Bousquet 2010). The goal is both the learning achieved during the process of model construction, and the jointly developed model that can provide information to enable better decision-making, policy and management planning to take place. It is generally recognized that more engaged stakeholders improve the results of the model, the usefulness to decision-makers, and its credibility, and learning value for the involved stakeholders and their community (Voinov & Bousquet 2010).

Participatory modeling, in this case SD modeling, falls under the wide umbrella of participatory research, where the focus is on the co-production of knowledge (Cornwall & Jewkes 1995; Pain & Francis 2003). The focus is not on methodologies, but on including a community as active participants in data generation, analysis, and use and ownership of results. Participatory research has a long history of applying different approaches and methodologies that range from the rapid rural appraisal in the mid-1970s, to participatory rural appraisal in the early 1980s , and participatory learning and action in the mid-1990s (Chambers 2008b). Chambers (2008a) observes that the differences between these approaches have diffused and there is now a creative pluralism of participatory approaches and methods.

Participatory SD modeling is distinct from other participatory methods in its emphasis on creating a model. Participatory methods are often bottom-up, community-, and stakeholder-driven (Cornwall & Jewkes 1995). While participatory modeling is intended to be bottom-up, it is often driven by scientists or a policy or governmental agenda. In participatory action research stakeholders learn by doing and implement changes in the system and learn from these changes (Chambers 2008a). However, with SD models the goal is to understand the complex system and to test policies and interventions using the model, which provides more information to decision-makers before taking action (Voinov & Bousquet 2010).

There exist a number of reasons why participatory modeling is useful, but there are also reasons to challenge the use of participatory modeling. First, to understand a complex system and its dynamics, it is critical to include those who participate in and are affected by the system, as well as incorporating multiple perspectives into the understanding of a system (Voinov & Bousquet 2010). This local knowledge can be qualitative and provide contextual information, or it can be quantitative and provide data (Chambers 2008b) needed to run scenario simulations. In developing countries, detailed and updated data can often be lacking or of poor quality. SD models are also complex and difficult to understand, but if stakeholders are involved in constructing it, the model and its results are easier to understand and trust. When involving local stakeholders the model also becomes more useful to that particular context as it meets the needs and interests of the local community (Cooke & Kothari 2001). Decisions regarding policies and interventions that are made based on the information generated by an SD model are more likely to be sustainable and implemented with less conflict and more success because they are based on local knowledge, updated and good data – and, importantly, the stakeholders have more trust in the model and its information (Voinov & Bousquet 2010). The strongest argument used to promote participatory methods is the contribution to empowerment and development of local communities since new skills are developed, and new and more collaborative interrelations are created (Cornwall & Jewkes 1995).

One of the challenges of participatory research, participatory modeling included, is that it has become so popular. Unfortunately sometimes it is only adopted in name. In reality, local stakeholders might only be participating to a minimal degree and only in a few stages of the research process (Pain & Francis 2003). Participatory research could also be tyrannical by achieving the opposite of inclusion, empowerment, and sustainability and could lead to unintended negative consequences (Cooke & Kothari 2001; Cornwall & Jewkes 1995). It is important to carefully consider who should participate and how, and who ultimately benefits. Critiques have also highlighted the minimal evidence of long-term effectiveness of participation leading to positive material and social change for vulnerable people. It is often unclear who is empowered (Cleaver 2001). Critiques also expose weakness in the methodology, the lack of rigor, reflexivity and validity (Pain & Francis 2003). All of these critical aspects apply to participatory modeling as well; they are assessed in this research in the methodology section.

There are numerous participatory modeling methods, including several approaches to participatory SD modeling (see Voinov & Bousquet 2010 for an overview). The chosen method in this thesis is GMB, which actively uses the SD language and provides guidelines and scripts on how to involve stakeholders during the entire process of initiating, developing, and using the model (Vennix 1996). GMB is presented in more detail in the methodology section.

2.3 Applying systems thinking and participatory system dynamics modeling to value chain analysis

An advantage of SD modeling is that it can be extended to include almost any process or system. Value chains are complex systems comprised of different nodes focusing on the physical flow of products, but also involving economic, social, natural, environmental, and institutional aspects, which are highly interrelated. Both the VCA framework and the systems thinking and modeling framework are interdisciplinary. In SD modeling, the interdisciplinary aspects of VC systems can be represented through different subsystems. Micro-analysis of these systems can be combined through a meso-analysis that focuses on the feedback relations between the different subsystems of the value chain. Systems thinkers see both the generic system and the specifics of the system (Richmond 1993; Richmond 1994). This captures both upstream and downstream feedback in the value chain. It is, however, important to have a clear boundary in SD models. In a company, the boundary is usually well known as a result of each of the workers having roles within specific departments. In agricultural value chains, setting the boundary can be more challenging owing to long and complicated value chains (Voinov & Bousquet 2010).

Value chains are dynamic and change constantly because of complex feedback relations, which are poorly captured in traditional VCAs. Delays in production, or delays caused by time to make decisions, are rarely taken into account in VCA. SD models incorporate these dynamics and enable *ex-ante* analysis of short-, medium-, and long-term effects of interventions. VCA maps and describes the chain and what influences it. It usually concludes with suggesting different types of upgrading strategies and interventions, but cannot evaluate the costs and benefits associated with different strategies. SD models address this by incorporating intended and unintended, as well as positive and negative effects of interventions. The conditions of participation in value chains can also be assessed using SD models. This is important information for policy-makers when considering different value chain interventions. This enables the conventional value chain approach to better address inclusion of smallholders and the effects on smallholders. Additionally, governance greatly affects value chain performance and is a central point in VCA. Different decision-making parameters such as power asymmetries, trust, and shared and individual goals can be included in an SD model as variables that drive change. SD models can be used for all four steps in VCA, focusing respectively on mapping, governance, upgrading, and benefits.

The participatory methods often used during VCA are adopted in systems thinking through GMB. This enables modeling with relevant active and enabling value chain actors. The participant selection and degree of participation during the GMB process is a foundation for achieving inclusive value chain development through SD modeling if interventions are implemented in practice. The stakeholders involved in the participatory modeling process will obtain a better understanding of the system they are actively involved in at a chain level. Collectively developed shared solutions can be communicated to the actors in the value chain, but also to governments and donors, for instance. If the participation is successful, the chosen value chain interventions might be more effective and sustainable since they have been thoroughly analyzed and tested through model simulations *ex-ante*.

Despite these favorable features of applying systems thinking and participatory modeling in VCA, there is little research combining these two frameworks, and especially not in a developing country context. McRoberts et al. (2013) provide the only identified example of participatory model building of a value chain in a developing country context. These researchers constructed an SD model focusing on small-scale dairy development in a rural community in Mexico and tested the possibilities of collective action to produce goat cheese by focusing on key biological and economic factors. They concluded that a system-based participatory approach can help in testing potential development and agribusiness interventions. The GMB process, however, only included researchers and development practitioners, and not the local dairy farmers in the Mexican community, hence it was not a truly participatory process.

Other examples of GMB processes that do not focus on value chains exist in developing countries. Olabisi (2010), for example, provides an example where researchers and community members enhanced their understanding of forest cover decline in the Philippines. The GMB process resulted in a more systemic understanding of the deforestation issue, which was able to generate more robust reforestation initiatives. Olabisi (2010) also highlighted that the participants learned from each other, and that this method avoided the challenge of experts lecturing community members, which is a top-down challenge between researchers, policy-makers, and community members. Huntjens et al.

(2014) had similar experiences with a GMB process to develop a climate change adaptation strategy within a water management project in Vietnam. Peipert et al. (2008) examined how socio-economic and ecological factors together determine a household's decision to adopt the use of biogas in India.

Examples of SD models focusing on agricultural value chains without the participatory focus also exist, but are few and of variable focus and quality. Rich et al. (2011) and presented and demonstrated the strengths of using an SD model in VCA by applying it to livestock systems. Hamza et al. (2014) used an SD approach to assess different commercialization scenarios in the goat meat value chain in Mozambique. Hamza and Rich (2015)[1] produced a practical handbook on how to apply SD techniques in value chains. Purnomo et al. (2009) provided an example of the teak furniture value chain in Indonesia and applied an SD approach to assess governance scenarios and their impact on the income of different actors. The research presented a simplistic view of value chain governance since it did not include aspects such as power asymmetries.

In supply chain management, SD modeling is utilized to a limited extent, also within agriculture (see e.g. Cloutier et al. 1999; Georgiadis et al. 2005; Minegishi & Thiel 2000). However, in supply chain management, SD models are mostly used to map the flow of goods and service to analyze dynamic decision-making often related to logistical challenges such as ordering behavior and other firm-level strategies (Angerhofer & Angelides 2000). Contextual factors such as the environment, institutions, and governance are missing.

To conclude, systems thinking and participatory modeling provide a comprehensive and detailed analysis methodology, and add valuable analytical rigor to a more inclusive value chain approach at a micro level and meso level. This is achieved by enabling *ex-ante* analysis of intended and unintended feedback upstream and downstream in the value chain over a short-, medium-, and long-term time horizon. Such an approach calls for research which applies and assesses the use of systems thinking and participatory modeling in VCA and development, with a particular focus on developing countries.

[1] Karl M. Rich is my supervisor and Kanar (Hamza) Dizyee is another PhD candidate of my supervisor. Together we have worked on developing the application of system dynamics modeling to value chain analysis with different focuses and applications.

3. METHODOLOGY

This methodology section presents the research design, and introduces the two case study areas in Nicaragua and Tanzania, together with the methods of data collection and processing. Discussion of the use of multiple methods includes reflections on the challenges of data collection, followed by reflections on validity and reliability of the research. To conclude this section, ethical research considerations are presented.

3.1 Research design

Development studies seek to understand the fundamental processes of dynamic social change by studying the interactions of the state, market, and society. An interdisciplinary perspective is an important aspect of international development research (Sumner 2006). This has been central in this thesis to capture the multi-dimensional and complex nature of value chains and smallholder participation. Knowledge and methods from both the social sciences (such as economics, geography, political science, entrepreneurship, systems thinking, and sociology) and natural sciences (such as animal and crop science) have been utilized. Overall, a qualitative research design was chosen, in which the links between goals, research questions, conceptual frameworks, choice of methods, and validity were constantly considered following Maxwell's (2013) interactive approach to research design. A case study approach was considered the best way of addressing the overall research aim of the thesis. A case study is an intensive study of a single unit for the purpose of understanding and giving a "thick" description of the case, thereby collecting detailed information on the dynamics present within that single setting to understand complex phenomena (Gerring 2004; Ghauri 2004). It is important to note that a case study can entail the analysis of several cases, as this research project demonstrates. A case study approach is valuable when testing hypotheses, and, according to George and Bennett (2005: 19) it is "particularly useful for theory development".

Two cases have been used to address the overall research aim, specific objectives and accompanying research questions of this study. In selecting of the Matiguás dairy value chain in Nicaragua, and the Mgeta dairy value chain in Tanzania as case studies, I followed different procedures. Before embarking on my PhD, I completed my Masters thesis that analyzed the Mgeta dairy value chain in the Morogoro region of Tanzania (see Lie et al. 2012), which utilized conventional VCA techniques. During this work, I recognized the strengths and weaknesses of this approach and started to search for and consider ways to strengthen the VCA approach during my PhD. In view of my in-depth knowledge of the Mgeta dairy value chain, as well as the continued struggle of the Mgeta dairy farmers to reach markets, I considered this to be a good choice of study to contribute to answering my overall objective, specifically focusing on theory development. The Mgeta value chain was initially selected on the basis of its particular nature as a smallholder dairy goat association aiming to add value to goat milk, which is unique in the Tanzanian setting (Bryman 2008).

The case in Nicaragua was selected at a later stage of my PhD research. This is in line with Maxwell (2013) who emphasizes that research design needs to be reconsidered and modified during the study if there are new developments or changes in any component of the research. Initially, the plan was to only conduct field work in Mgeta, Tanzania, but, owing to changes in direction of the research towards systems thinking, I decided to add another case study to apply and test the desired theory and methodology of participatory SD modeling. The theoretical and conceptual framework and research questions were changed accordingly. I initiated a collaboration with the International Center for Tropical Agriculture (CIAT) owing to their experience in working with VCA and development focusing on smallholders and often utilizing participatory approaches. Together, we identified the dairy value chain within the Matiguás municipality in Nicaragua as a suitable case to answer my overall and specific objectives and research questions through the chosen methodology of GMB. The dairy value chain in Matiguás municipality was selected because it is part of the largest milk-producing area in Nicaragua, the so-called *via lactea* ("milky way"), where 20% of the country's milk is produced, and is primarily a smallholder, cattle-based area (INIDE-MAGFOR 2013). The changes in the research design resulted in three articles focusing on the Nicaragua case, and one applying to the Tanzania case[2].

Despite the different selection criteria for the two cases, both represent typical situations of smallholder dairy producers facing challenges with accessing or continuing to participate in dairy value chains, and can therefore be referred to as *exemplifying cases* (Bryman 2008). Both Nicaragua and Tanzania are low-income countries driven by smallholder agriculture where livestock-keeping represents an important livelihood strategy for many smallholders (MAGFOR 2013; Njombe et al. 2012). Although the two cases differ in terms of economy,

[2] Other articles have been previously published based on the Tanzania case (see Lie et al. 2012; Lie 2016; Msalya et al. 2016)

politics, culture, and ecology, this does not impact on the research design since I am not following a comparative case study research design, but rather focus on maximizing learning by testing and developing theory and methods through the use of two separate case studies (George & Bennett 2005). The cases can therefore also be classified as *critical cases* since they are used to test and develop theory and methods based on the overall hypothesis that systems thinking and modeling will strengthen the conventional VCA framework both theoretically and empirically (Bryman 2008). The cases therefore represent different types of case studies (unique, exemplifying, critical) based on the particular focus of the analysis. One critique of case studies is the difficulty of drawing general conclusions from a single case study. The goal of this case study design is not the generalization of specific outcomes of the case study analyses, but rather analytical generalization based on the testing and development of theory and methods focusing on the use of systems thinking and participatory modeling for inclusive VCA (Bryman 2008).

A case study approach using multiple research questions requires the use of a wide range of data sources and multiple methods of processing the necessary information. A mixed methods approach was chosen, gathering both qualitative and quantitative data (Creswell 2014). Qualitative data collection involved key stakeholder interviews and focus group discussions. GMB as a form of focus group discussion was used to collect quantitative data. This is a clear departure from the use of surveys, which is probably the most common way of collecting quantitative data. How each method of data collection was used will be explained after the case studies introductions.

3.2 Study areas

3.2.1 Mgeta dairy value chain in Tanzania

Mgeta is a set of rural villages located in the Uluguru Mountains in the Morogoro region of Tanzania. Four villages were selected to focus on during the research: Nyandira and Ndugutu in Nyandira ward, and Tchenzema and Kibagala in Tchenzema ward. These villages lie approximately 50 kilometers from the closest town, Morogoro, which is included in this research as a potential market outlet (see map of the study area in Figure 3 below). In these four villages, an estimated 6500 people (NBS 2012b) mostly depend on semi-subsistence farming for their livelihoods. The farmers in Mgeta struggle with inconsistent incomes as a consequence of climate variations and a lack of alternative income sources.

There is high pressure on land and limited opportunity to expand agricultural activities. Food- and nutrition insecurity is a major concern in the Mgeta area (Eik et al. 2008).

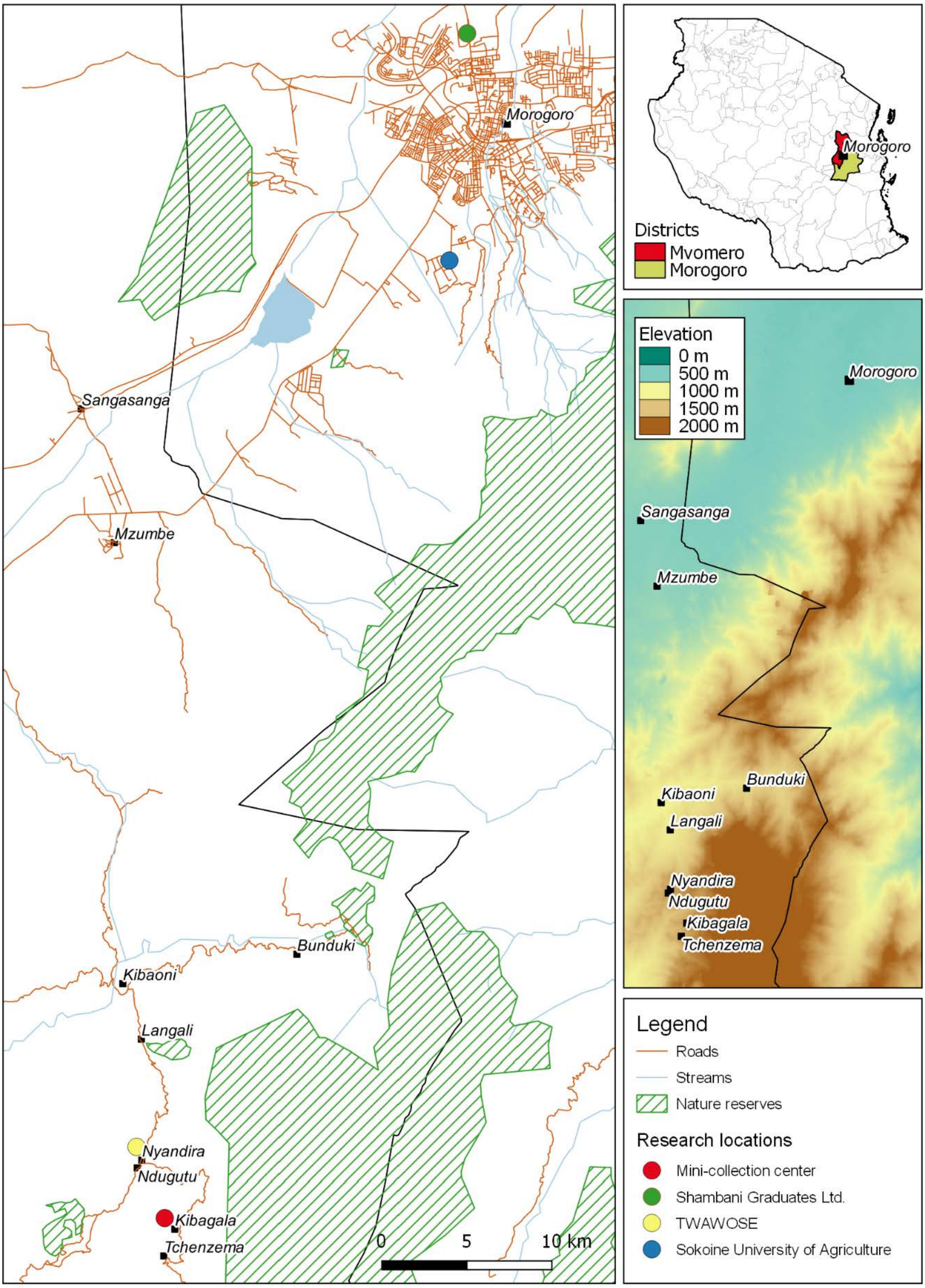

Figure 3: Map of the study area in Tanzania. Source: L. K. Grimsby 2017

Norwegian dairy goats were introduced to Mgeta in the late 1980s through research collaborations between the Sokoine University of Agriculture (SUA) and the Norwegian University of Life Sciences (NMBU). The goal of the project was to improve farmer incomes and household nutrition through consumption and sale of goats and milk. Small quantities of milk can improve the nutritional status for smallholders, which is especially important for children, pregnant or nursing mothers, and sick people. Sale of milk can provide a continuous flow of income, and a valuable addition to seasonal sale of vegetables. There are about 450 dairy goat farmers with about 2000 dairy goats in the area and they produce between 500 and 1000 liters of milk daily. On average, a dairy farmer in Mgeta keeps four to five goats, which classifies them all as smallholders. In Tanzania, smallholder farmers are defined as those who own less than 20 hectares of arable land, own between 1 and 50 head of cattle, and/or between 1 and 100 goats/sheep/pigs (URT 2012). Figure 4 shows a typical goat shed in Mgeta and illustrates the poor agricultural and infrastructure conditions, with little land availability in the area.

Figure 4: Goat shed in Nyandira village surrounded by houses, a vegetable garden, and fruit trees. Source: Helene Lie

In 2010, the number of dairy goat keepers and dairy goats reached a level that allowed for collecting and processing of goat milk twice a week to sell during the local market days. The dairy goat association, Twawose, based in Nyandira, was in charge of this with support from SUA, and functioned as a milk collection and processing cooperative as well as a farmers' association. The cooperative was established in 2010 and has had a steady number of approximately 68 members since. The board is elected each year and holds regular meetings. The board members manage and operate the milk collection and processing, with the exception of one member who functions as a manager. The different roles are rotated among the members, who have received training and support from SUA and other organizations. There is active participation of both male and female members in the association and in the board. The farmers individually and collectively still lack critical assets such as knowledge about marketing and business management. They experience power struggles within the association, and face infrastructural challenges such as limited electricity and poor road conditions, which limit access to larger, more distant markets (Lie et al. 2012).

Dairy goats are not the main source of milk in Tanzania. There are 22.8 million cattle, and 15.2 million goats, of which only about 400,000 are dairy goats (NBS 2012a). However, dairy goats are often more accessible to smallholder farmers, as their smaller size makes them suitable for smallholder (subsistence) farming. Goats are also cheaper than cows to purchase and relatively inexpensive to keep as they require less maintenance, less fodder, smaller plots for grazing, and can easily adapt to mountainous conditions. The levels of risk are also reduced when keeping goats since the investments are dispersed over greater numbers of animals. Goats also reproduce faster than cows (Peacock 2005), and goat milk is considered by some to be healthier than cow milk (Zervas & Tsiplakou 2013). Goat milk fat and proteins have a higher nutritional value than cow milk and are digested more easily, allowing most lactose intolerant people, for example, to consume goat milk. It is also easier for infants with mothers who cannot breast feed, or sick people, to digest goat milk than cow's milk (Zervas & Tsiplakou 2013). On the other hand, goats produce less milk per day than cows, but this can be overcome by keeping more goats.

Adding value to goat milk is seen as one way of securing higher income for smallholder farmers in Mgeta, as well as supplying nutritious milk to consumers. Several upgrading strategies have been identified and implemented with varying degrees of success. This research builds on a VCA conducted in 2010–2011 (see Lie et al. 2012) and on follow-up research regarding implementing and assessing the upgrading strategy of supplying drinking yogurt to nearby primary schools (see Lie 2016). Numerous studies have been published on dairy goats in Mgeta, mostly concerned with breeding, feeding, and climate change effects (e.g. see Eik et al. 2008; Kifaro et al. 2014; Nziku et al. 2016). Currently, the focus is on partnering with a commercial dairy processor, Shambani Graduates Ltd., to overcome the challenges faced by the Mgeta dairy goat farmers and to utilize the excess milk produced in the area (see Msalya et al. 2016). Despite being part of several research projects that have implemented various value chain interventions, the Mgeta dairy goat farmers and their association struggle with accessing larger markets. This is an example of policy resistance among value chain stakeholders and where decision-makers have adopted a more linear, event-oriented way of thinking. Applying systems thinking and SD modeling, especially focusing on governance, could be a good way of addressing persistent challenges in the chain.

3.2.2 Matiguás dairy value chain in Nicaragua

Matiguás municipality lies in the Matagalpa department, centrally located in Nicaragua (see map in Figure 5). Matiguás town lies about 160 kilometers from the capital, Managua. In Matiguás municipality, about 80% of the population of 42,300 are cattle-keeping households following a dual purpose cattle system concentrating on both meat and milk. Approximately 60% of milk producers in Matiguás are small-scale, while 20% are medium-scale producers, and the remaining 20% are large-scale (Polvorosa & Flores 2015). In Nicaragua, small-scale producers typically own less than 14 hectares of land, between 2 and 20 cows, and produce about 20 liters of milk per day. Medium-scale producers own between 14 and 70 hectares, and produce around 50 liters of milk per day. The definition of small- and medium-scale farmers is based on the official national definition used in the agricultural census (INIDE-MAGFOR 2013) and is based on land ownership.

There is limited land available in Matiguás for agricultural expansion. Utilizing the land more efficiently, without depleting it, is important to increase the income of small- and medium-scale farmers. Figure 6 shows a medium-sized cattle farm in Matiguás and illustrates how animals are kept and the conditions of farm infrastructure in the area. It is equally important to ensure that the small- and medium-scale farmers keep up with the production standards set by the dairy industry, in order to enter or to keep participating in the high value dairy chain. In Nicaragua, dairy is an important part of the culture as well as a large industry. National milk production increased by 4.6% during the period 1998–2012 and was estimated to be between 2 million and 2.3 million liters per day in 2012, with less

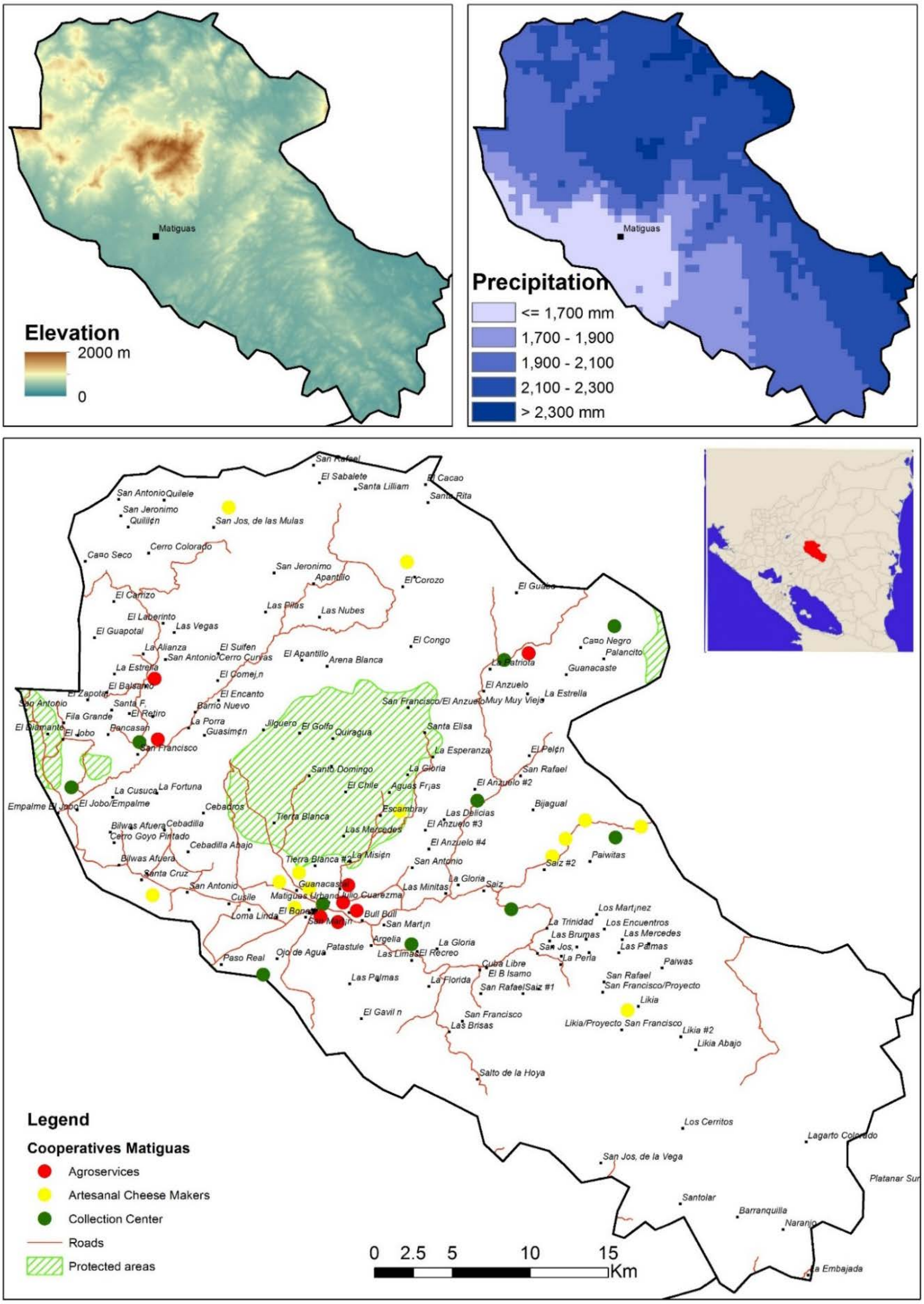

Figure 5: Map of the study area Matiguás municipality. Source: CIAT 2015

than 50% being absorbed by formal processing plants (Holmann 2014). There is increasing demand for pasteurized milk nationally, as well as from other countries in Central America and the USA (Polvorosa & Flores 2015). The Nicaraguan government prioritizes improvement of the cattle and dairy sector, which contributes to 13% of the national GDP, as it can assist in poverty reduction, food security, economic development, and ecosystem restoration (MAGFOR 2013).

Figure 6: Medium-sized cattle farm in Matiguás, Nicaragua. Source: Helene Lie

Matiguás is part of the *via lactea* ("milky way"), consisting of four municipalities in which over 20% of the country's milk is produced (INIDE-MAGFOR 2013). In Matiguás, approximately 100,000 liters of milk are produced per day, but with high annual fluctuations. The dairy value chain in Matiguás is complex with numerous actors in different nodes of the chain. It is often divided into three different chains. One focuses on milk collected by cooperatives and supplied to the dairy industry in Managua. The second concentrates on informal collection and processing for consumption and sale locally. The third is concerned with the collection of milk that is processed into fresh cheese and exported, primarily to El Salvador, for further processing. This research focuses on the first value chain and involves five cooperatives and several private actors that collect milk from more than 1000 milk producers. About 70% of the milk producers are organized in a cooperative (Alcaldía Municipal de Matiguás 2011; Polvorosa 2013). The number of dairy processors in Nicaragua has over the past few years been reduced from five to three, owing to recent acquisitions and mergers.

Several analyses of the Matiguás value chain have been conducted by institutions such as Heifer and Tropical Agricultural Research and Higher Education Center (CATIE) (Velásquez & Manzanarez 2014), Central American University (UCA) and the research and development institute Nitlapan (Flores et al. 2011; Polvorosa 2013), and by the local municipal government (Alcaldía Municipal de Matiguás 2011). These have suggested a number of upgrading strategies including a focus on breeding, feeding, milk quality, and milk collection and processing. However, none of these studies were able to successfully assess and evaluate potential outcomes of the different interventions, which makes it a good objective and case for this research project.

3.3 Methods of data collection and processing

Data collection took place in Mgeta, Tanzania from December 2013 until April 2014, with a follow up visit of 1.5 weeks in January 2015. In Nicaragua, data was collected between March and June 2015, with a follow-up visit of 1.5 weeks in April 2016.

3.3.1 Group model building

GMB is a participatory method of jointly developing an SD model with relevant stakeholders. The goals of a GMB process are to create a climate for group learning about the problem and the focal system, and to foster consensus and commitment to decisions regarding policies and interventions in value chains based on an SD model (Rouwette & Vennix 2006; Vennix 1996). The process is particularly useful in value chains that have many stakeholders with different opinions and different intervention options, which often leads to policy resistance. It is also useful in environments where data is scarce. Constructing SD models requires in-depth and detailed information about the value chain and its systems, which might not be readily available or which is outdated. GMB is then a helpful way of collecting the necessary data. The stakeholders can be part of the entire process or of only selected parts (Hovmand 2014).

During this research, the value chain stakeholders were included during the entire modeling process. SD provides the GMB participants with a shared language to understand complex systems such as value chains. Participating in a model building exercise can improve the stakeholders' understanding of the system and of the intended and unintended consequences of their actions in the short and long run (Vennix 1996). It also provides them with an opportunity to influence decision-making about value chain policies and interventions, an important aspect of smallholder agency.

This GMB process followed the Vennix (1996) and Sterman (2000) methodological framework, consisting of five steps. The modeling process starts with identifying and defining a dynamic problem. It continues with the formulation of dynamic hypotheses or theories about the causes of the problem, which lays the foundation for the focus and scope of the model. The third stage results in the formulation of a formal model that can be simulated using a computer program such as Vensim[3], Stella[4], or iThink[3]. Fourth, the model behavior is tested and evaluated, before finally running scenarios that contribute to policy analysis. Additional activities include assessment of the process, report of insights, findings, and recommendations (Sterman 2000; Vennix 1996). SD modeling is a structural approach. By using a GMB process, it is also interactive and allows for an iterative process that facilitates inclusion of various stakeholders during each stage of the process. In addition, there are clear guidelines on who should be in the facilitation team and what their roles entail. A facilitation team typically consists of the lead facilitator, a recorder who takes detailed notes in each session, a modeler, a process coach who pays specific attention to the group's process and dynamics, and a gatekeeper who is the liaison between the facilitation team and the participants. One person could take on several roles, but a minimum of two people is advised, and more if working with a large group (Vennix 1996). Rigor is added to this participatory modeling effort by following the tried and tested process of GMB research.

Owing to the importance of presenting the participatory modeling process in detail, as well as the novelty of the approach and lack of usage in value chain studies, a separate article in this thesis (article 2) has been devoted to describing the process. The details of the GMB process in Matiguás, Nicaragua and an assessment of important participatory modeling principals are offered in the article, adding to the recoverability and reliability of the

[3] From Ventana Systems Inc. Available at http://vensim.com/
[4] From iSee Systems. Available at https://www.iseesystems.com/

participatory research. Only an overall summary of the most important participatory aspects are discussed here.

The GMB process consisted of four sessions taking place between March and June 2015, with a follow-up session in mid-April 2016. Each meeting session was carefully planned, and can be seen as a focus group discussion with clear goals for each session. Stakeholders from each of the nodes in the value chain and from the enabling environment were identified, together with a gatekeeper, a local project manager, and were invited to participate in the sessions. On average, 13 participants took part in the sessions. This is a fairly large group for GMB projects (Vennix 1996), but it was necessary since the Matiguás value chain consists of many actors and enablers. The GMB group included small- and medium-scale farmers (four participants), three from cooperative management, one local processor, three local government representatives, and seven from institutions working on value chain interventions, such as Heifer International, CIAT, CATIE and Nitlapan. This is a representative group of the dairy value chain in Matiguás, except for the limited inclusion of women. Only 14% of the participants were women. The goal was to involve more women, but in view of the male dominance in the cattle sector in Nicaragua, this proved to be challenging.

Attendance at each of the GMB sessions varied, despite the goal of keeping the same participants throughout all the sessions. Varying degrees of commitment during the process is commonly experienced as a result of other responsibilities, changing interests or willingness to participate (Cleaver 2001; Cornwall & Jewkes 1995). Despite the participation variability, participants also asked if others could join since they found it interesting. These participants were welcomed. The modeling process also involved a reference group consisting of researchers from CIAT based in Managua, Nicaragua and Cali, Colombia (the location of CIAT headquarters), and key stakeholder interviews (presented below).

GMB Session 1 focused on introducing the research focus, agreeing on value chain goals, and identifying and selecting a problem with accompanying causes and consequences. Fifteen problems were identified individually by the participants, followed by voting to select one problem to focus on. Reference modes were developed for the selected problem of deficient feeding systems. GMB Session 2 introduced the language of SD and started building the structure of the dairy value chain system in Matiguás. GMB Sessions 3 and 4 were concerned with validating the structure and adding and validating data produced in groups. In Session 4, a small evaluation of the overall process was also conducted. Between each of the sessions, the modeler and facilitator, in collaboration with the reference group, used the information received to further develop the model to report and verify in the next session. Session 5 was conducted almost 10 months after the fourth session. We had not yet reached the point of discussing preliminary results by the end of Session 4 as had been initially planned; therefore, we followed up with a fifth session to follow the principles of participatory research. The focus of this final GMB session was to verify the model and report back on preliminary results and to plan the way forward. A concluding evaluation of the overall GMB process using a small survey was also conducted.

Although the GMB process and each session were planned in detail, an interactive and iterative research design allowed for changes during the process. A detailed script (Andersen & Richardson 1997; Hovmand et al. 2012; Luna-Reyes et al. 2006) for each session was developed which set the goal for the session, the techniques applied (plenary discussion, round robin, small-group work, developing CLD and stock and flow structure), and the timing. See script for each GMB session in Appendix 1. Different degrees of participation occurred during each session, partly resulting from knowledge and power differences among participants (Gaventa & Cornwall 2008), and partly from challenges with the systems language. Different approaches, such as smaller group discussions, were used to address this challenge.

Decisions in the modeling process were taken based on consensus among the GMB participants. The main problem was identified using round robin discussions and ranking. Otherwise, model structure and quantitative data needed for parameterization was discussed mostly in small groups until agreement was reached and then presented in plenary. Here it was discussed further until overall agreement was reached. Sometimes, data from the national agricultural census for Matiguás (INIDE-MAGFOR 2013) was used as a starting point for discussion. Three facilitators guided the group discussions to ensure that everyone could and did participate. This was necessary to be able to assist participants who did not read and write, and for each group to have a facilitator when doing small group work. In participatory processes, it is common that the researcher becomes more of an overall facilitator, process coach, and modeler (Voinov & Bousquet 2010), which was the case during this GMB process. The processes were documented by a recorder, the researcher, and by the participants. After each session, the different notes were transcribed and combined with pictures of the session and the outputs of each session, to ensure recoverability of the research.

3.3.2 Focus group discussions

A focus group is an interview style where a small group of individuals is led in a discussion of a particular topic (Berg & Lune 2012), such as the GMB discussions in Matiguás. In Mgeta, 12 focus group discussions were organized with current and potential male and female milk suppliers from the four study villages (Nyandira, Ndugutu, Tchenzema, Kibagala). Additionally, there were two focus group discussions organized with the association leadership who also carry out the roles of milk collectors and processors. There were, on average, five to six participants in each focus group. Discussions centered on access to resources, relations with other stakeholders in the chain, and development of and decision-making in the goat milk value chain. The discussions ranged from being loose and open-ended, to being structured by using flip charts to facilitate discussion and scoring of relational aspects between the actors in the chain.

The focus group discussions were supported most of the time by two research assistants. One primarily served as a translator, while the other took notes and observed the group together with the researcher. Conducting a focus group in Swahili with elements of Luale, the local language, was challenging. However, I did know basic Swahili so I could follow the overall theme of the conversation, which made it easier to facilitate the direction of conversation and to pick up when there were interesting elements being discussed. But language challenge was one of the key reasons for sometimes choosing a more structured approach in the focus group discussion.

3.3.3 Key informant interviews

I conducted key informant interviews in both Tanzania and Nicaragua. Each interview was semi-structured, using interview guides tailored to each respondent. Respondents were selected both purposefully and using a snowball method (Maxwell 2013). I started with identifying important actors (such as cooperative management, processors, and enablers) in the two value chains under study. These respondents identified others with extensive knowledge about specific aspects of the value chain important to this research. Key informants were also used to identify potential participants for the focus group discussions.

In Tanzania, 13 key informant interviews established a foundation for the focus group discussions, as well as supplemented the data from the focus group discussions. Interviews were conducted with the dairy company Shambani Graduates Ltd. in Morogoro, extension workers, village leaders, and others with extensive knowledge of the Mgeta dairy value chain. In addition to the GMB sessions in Nicaragua, key informant interviews were conducted before and during the GMB process in Matiguás with the leadership of two different cooperatives, an informal milk processor, various dairy product sales outlets, and various local credit institutions. In Managua, interviews were held with a private dairy industry actor and the Nicaraguan Chamber of the Dairy Sector. These interviews provided background and in-depth knowledge about the various actors and processes in the value chain and also discussed specific aspects to be covered in the SD model.

In both countries, field assistants also functioned as translators when needed. Some interviews were conducted in English and others in Swahili or Spanish. Because an extra link is added to the communication process, the risks of misunderstandings between the interviewee and the researcher increase (Desai & Potter 2006). However, having basic knowledge of both Swahili and Spanish helped me so that I could follow the answers of the respondents and use the translation as a supplement. I also found that the assistants were of great help since they were familiar with the areas, especially while doing field- work in Tanzania. My assistant provided insightful knowledge that supported my understanding of the activities and culture in Mgeta. A recording device was used during interviews when I felt it was important to have verbatim recordings, and on condition that the respondent was comfortable with its use. I always took notes during the interviews. Notes from interviews and other observations and thoughts were transcribed as soon as possible after the interview, and were combined with transcribed recordings of interviews when applicable. The data was analyzed while in the field to guide subsequent interviews, and when returning from the field by using codes identified based on the research questions.

3.3.4 Participant observation

The group discussions and interviews in Tanzania were backed up by observations of market promotions and of day-to-day operations in Mgeta. I spent time in Nyandira, the village where the dairy goat association has their office and production building. That enabled me to observe daily operations in Mgeta, and to attend 10 association leadership meetings, and two general association meetings. This provided firsthand insights about how information was distributed, and observations of how conflict and challenges were handled. This afforded deeper understanding of the different relations and interconnections in the Mgeta dairy value chain, which was especially important when analyzing value chain governance. I did not spend as much time in the field in Nicaragua as in Tanzania as a response to different research questions and methodological approaches. Other studies had previously mapped the value chain and that provided me with a good starting point. I did, however, spend a few days on two different occasions visiting different dairy farms, collection centers, cooperatives, informal processors, and different types of sales outlets of dairy products to get an understanding of the actors, activities, context, relations, and challenges in the Matiguás dairy value chain.

I took notes about what I observed in the field, as well as noting general thoughts and reflections. This helped me in preparing individual and group interviews, to be more culturally sensitive when asking questions, and when finding locations and appropriate times for the different interviews.

3.3.5 Secondary data

Primary data from Tanzania was supplemented by records from the Twawose dairy goat association, detailing information such as the amount of milk collected, amount of yogurt produced, market outlets, and number of suppliers. Background information about the dairy sector in Tanzania from the Ministry of Livestock and Fisheries Development and other institutions provided contextual information, and is cited when used.

In Nicaragua, the national agricultural census includes data on cattle production and provided information about the number of cattle-keeping households in Matiguás. It also provided data on the number of calves, bulls, and heifers in the Matiguás municipality. This information was used as a starting point in the GMB process. Other secondary information, such as previous value chain analyses of the Matiguás dairy value chain conducted by Heifer, CATIE, INIDE, and the local government in Matiguás, provided a valuable starting point for my analysis, and is always cited when used.

3.3.6 Validity and reliability

The use of multiple methods enables triangulation of data, and strengthens the research by reducing the weaknesses or biases associated with one particular method (Maxwell 2013). Triangulation is considered one of the defining features of a case study (Ghauri 2004). During this research, data triangulation was possible through the use of data from individual and group interviews, observations, and secondary data. This improved the validity of the research, which, according to Silverman (2005: 380), is "the extent to which an account accurately represents the social phenomena to which it refers". This is accomplished by using several methods that, together, establish credibility and trustworthiness in the data. Triangulation has also been used to reduce the likelihood of misinterpretation arising from language and cultural differences.

In Nicaragua, respondent validation through the participatory model building process was used to improve the quality of the model and data used in the model (Ryen 2002). The structure of the model and its boundary was validated during different GMB sessions and the behavior of the model was validated during the last GMB session by running simulations in real time during the session and obtaining participant verification of the model's behavior. The model has further been validated through extreme condition tests and sensitivity analysis of key variables and by ensuring dimensional and parameter consistency (Forrester & Senge 1980; Sterman 2000).

When conducting qualitative research, the terms "reliability" and "validity" are used as quality criteria for the research project. Reliability concerns how the data is collected, used, and assessed, by reflecting on the degree of consistency when different observers, or the same observer on a different occasion, reach the same conclusions (Silverman 2005). To increase the reliability of this research, effort has been put into ensuring transparency with regard to how the research has been conducted, as well as describing the research design in detail in order to ensure that it, along with methods of data collection, are accessible and understandable. For example, Article 2 of this thesis titled "Participatory system dynamics modeling for dairy value chain development in Nicaragua" is dedicated to presenting and assessing the participatory model building of the Matiguás dairy value chain. The reliability of this research is further strengthened by being self-critical and reflective during the entire research process.

3.4 Research ethics

Consideration of research ethics is not a separate part of a research design; it must be included in every step of the research project, from selecting research objectives, methods, and research sites, to choosing how data is collected, stored, and presented (Maxwell 2013). Research ethics have been considered from the beginning until the end of this research project. Doing ethical research in a foreign setting is, according to Scheyvens et al. (2003: 139), "about building mutually beneficial relationships with people you meet in the field and about acting in a sensitive and respectful manner". While in the field, all reasonable attempts were made to provide full disclosure about my research interests and aims, to be context-sensitive, and to consider how this research and relationship would affect the members of the community being researched. This was particularly important for me as a white female researcher conducting research in foreign countries with different cultures to mine. Scheyvens et al. (2003: 139) stress that "ethical research should not only do 'no harm', but also have potential 'to do good', to involve empowerment", which is the core aim of my research focusing on improving smallholders livelihoods through inclusive value chain development. Voluntary participation and informed consent are important ethical aspects of fieldwork. These were secured orally from the participants of each focus group and individual interviewees before any discussions began. I also explained beforehand the goals of the research and assured participants that their identities would be protected during the course of the research.

Formally, the research activities in Tanzania and Nicaragua were granted research permits from the Norwegian Center for Research Data (NSD), which functions as the data protection official in Norway, covering ethical standards in relation to privacy protection. Additionally, research permission to conduct research in Tanzania was granted by SUA on behalf of the Tanzania Commission for Science and Technology. In Nicaragua, I was conducting research under the "CGIAR Research Program Livestock & Fish" where CIAT was one of the lead partners of the Nicaraguan dual purpose cattle value chain project. CIAT had the necessary research permits in Nicaragua. I have also paid attention to and followed the rules set by the National Committee for Research Ethics in the Social Sciences and Humanities in Norway.

4. SUMMARY OF ARTICLES

4.1 A systems perspective on governance and partnership in smallholder agricultural value chains

Article 1 advances the analytical framework of governance in value chains, using a systems based approach to partnerships. Partnerships of different kinds can be an attractive solution for smallholder farmers seeking to upgrade their positions in agricultural value chains. When smallholder farmers move from local market arrangements or from coordination through farmer organizations, to partnering with the private sector or in a public–private partnership, governance relations can become more captive in nature, leading to greater asymmetries in power relationships. The inclusion of new actors comes with a need to reconcile different interests and governance structures in the value chain. It is therefore important to carefully consider changes in value chain governance, and the intended and unintended effects that can arise when upgrading agricultural value chains through new partnerships.

The article extends a standard systems thinking archetype known as "accidental adversaries" (AA) to highlight the activities conducted by partners in a value chain and how local decisions can impact on those of partners. This can result in either achieving or obstructing the overall partnership goal. A second governance model further addresses some of the institutional aspects that underpin transactional dynamics in the value chain by focusing on power asymmetries between partners. These two systems models offer insights into the intended and unintended consequences of decisions made in a complex and dynamic value chain system with multiple actors working towards both their own objectives and a common overall goal. This is demonstrated by applying the models to the smallholder dairy value chain in Mgeta, Tanzania. Well-intended decisions made by the dairy goat farmer association that collects and processes goat milk for the local market, had unrecognized and unintended consequences that led to difficulties in accessing larger markets successfully. The potential of entering into a partnership with a commercial processor is further explored by using the two models, which illustrates how issues such as trust and a common vision play vital roles in the outcomes of decisions made by different actors.

The models can therefore be used to identify weaknesses in the governance structure of new or existing partnerships by analyzing the consequences of decisions made. They can also support the identification of leverage points and interventions that are important to achieve successful value chain partnerships. By addressing the means through which partnerships affect value chain governance, as well as its potential effects on smallholder farmers, the two systems models provide insights concerning actions that can support the partners and their enablers, in achieving a good foundation for establishing and implementing a successful value chain partnership. Extending this approach to a quantitative model could provide more in-depth information by testing effects of different interventions over the short, medium, and long term.

4.2 Participatory system dynamics modeling for dairy value chain development in Nicaragua

Article 2 aims to demonstrate and assess how a GMB process can be applied in building SD models that can contribute to pro-poor and inclusive value chain development. The article provides a detailed example of the participatory SD model-building process applied in the analysis of the dairy value chain in Matiguás, Nicaragua. The article presents in detail the methodology chosen, which included five GMB sessions, the use of a reference group, and key informant interviews to backstop the GMB process. The goals, activities, participants, and results of each of the sessions are presented and discussed. The article confirms several challenges with and benefits of participatory modeling. First, it is a time- and resource-consuming method. There are also challenges in the participant selection process in a value chain with many stakeholders to achieve full participation by all. Language and culture differences were found to be a challenge, which is common when doing research in developing countries. Despite this, the participating stakeholders were actively involved in and positive about the model building process. A carefully planned, but iterative, research design facilitated this result.

The GMB process resulted in a qualitative conceptual model (see Article 3), which was further developed into a quantitative SD model for scenario analysis (see Article 4). The GMB participants, and others with an interest, can have access to the model online[5] where they can run their own scenarios. In addition to the model outputs, the participatory model building process assisted the different value chain stakeholders to develop a deeper understanding of the complex and dynamic structure of the value chain, and differences in

[5] Available at: https://sims.iseesystems.com/helene-lie/dairy-value-chain-development-in-nicaragua

perceptions across actors. The participants provided updated and location-specific data that otherwise would have been difficult to obtain. By actively being part of the entire modeling process, the participants developed a greater understanding of the value of modeling as a tool for decision-making and priority setting. The article concludes that, based on the experience in Nicaragua, participatory model building of value chains can be a powerful tool to support policy-makers and other actors working with inclusive value chain development in developing countries.

4.3 Modeling dynamic processes in smallholder dairy value chains in Nicaragua: a system dynamics approach

Article 3 aims to identify and explain the dynamic processes in the Matiguás dairy value chain through a qualitative conceptual SD model. The participatory model building process identified feeding systems as the main problem in achieving the value chain goal of increasing the production of milk, both in terms of quality and quantity, as a means of achieving higher income for the actors involved in the value chain. The GMB process further identified four subsystems of the value chain, which resulted in four modules focusing on: 1) herd dynamics, 2) milk processing and sale, 3) costs and revenues, and 4) feed dynamics. The herd dynamics module provides details on cow production from birth of calves to mature dairy cows. The milk processing and sales module focuses on milk production and the supply of milk to the informal and formal sector. The costs and revenues module combines all costs involved in the model from producing cows, feeds, and milk, to revenues from milk and cow sales. It also includes investment assumptions of the ways that short-, medium-, or long-term profits are achieved. The feeds module presents the options of using traditional vs. improved pasture and concentrate.

The article highlights various feedback loops present in the Matiguás dairy value chain using the conceptual SD model. Changes in the feeding system will have consequences for the three other subsystems of the value chain. Increasing the use of improved pasture or concentrate, enhances cow production through improved fertility and reduced death rates, and increases milk production through higher cow productivity. Importantly, the feeding system is closely linked to the profits obtained by dairy farmers since improved pastures and concentrates are more expensive than traditional pasture. Introducing these improved feeding practices might increase milk production, but it is difficult to say whether, or to what degree, it will increase the profitability of small- and medium-scale producers. After presenting different reinforcing and balancing feedback loops in the value chain, the article concludes with a research strategy to test the impacts of (i) increasing the number of dairy cows, (ii) increasing the use of concentrates in the dry months, and (iii) increasing the amount of land used for improved pasture on the income of small- and medium-sized producers.

4.4 Quantifying and evaluating policy options for inclusive dairy value chain development in Nicaragua: A system dynamics approach

Article 4 presents the quantitative system dynamics model of the Matiguás dairy value chain in Nicaragua. The model was used to test and evaluate the short-, medium-, and long-term impacts of specific interventions and policies in the Matiguás dairy value chain with the goal of strengthening the competitiveness and inclusion of small- and medium-scale producers. Three types of scenarios were considered to increase milk production and farmer income. Scenario 1 examined increasing the use of concentrates during the dry season when milk production is low. Scenario 2 assessed the impact of increasing the amount of land used for improved pasture. Scenario 3 simulated the effects of investing in additional dairy cows. Combinations of scenarios were also considered. Metrics of analysis included the computation of farm-level cumulative profit and seasonal milk production.

Model simulations reveal that the increased use of concentrates (scenario 1) raises producer milk productivity by 11% in the long run, but results in a loss for farmers (-3% in the long run). This suggests that the current price of concentrates is too high to make it viable for producers to invest in concentrates. However, 20% reduction in the price of concentrates would result in profitable milk production. Concentrates also greatly increase milk production during the dry season, as well as during the occurrence of drought. Investments in improving pasture quality (scenario 2) result in an increase in milk yield, but similar to scenario 1, they are not profitable, due to high initial investment costs. By also making investments in training farmers in pasture management, long-term milk yields and profits increase by 10% and 7%, respectively. It also results in a 30% and 35% increase in milk production in the wet and dry season, respectively. Investing in additional dairy cows (scenario 3) is not profitable and does not lead to any change in milk production, and hence should be discouraged by policy makers until higher quality and quantity feed is available.

These results suggest that policy makers should acknowledge that intensifying feeding systems to improve milk yields is only profitable in the long term and requires support in the interim to induce and sustain these investments. This means that during the first phase (initial five years) of investment, producers need to be supported by government, development organizations, and/or the private sector. Alternatively, policy makers could consider strategies that reduce input costs to obtain positive returns in the short-term. Similarly, an aggressive policy strategy (i.e., simultaneously applying all scenarios – improved pasture + concentrates + training + lower concentrate prices) generates strong positive profits in the short and long term, but also requires higher investments and could be costly relative to more cost-effective alternatives.

Reducing the price of concentrates might be possible through bulk buying or local production. National polices could be put in place to subsidize concentrates when drought occurs as a temporary policy that can be put in place quickly. Policy makers can support adoption of improved pastures by investing in participatory training, like farmer field schools, model farms, and training of technicians. Improving access and availability to sources of medium- and long-term credit would greatly increase the number of farmers able to invest in improved pastures, which is currently limited in Matiguás. Even cooperative members usually only have access to short-term credit. Collaborating with cooperatives to implement suggested policies will be crucial for successful implementation, and will strengthen the position of cooperatives in the dairy sector. Hence, promoting membership in cooperatives will be vital for inclusive dairy value chain development in Matiguás.

This participatory SD approach addressed a major analytical shortcoming in traditional VCA and provides decision makers with an improved platform for planning and policy formulation. The mostly qualitative value chain analysis framework used in previous analyses does not allow for quantification and testing of short-, medium-, and long-term effects and tradeoffs between different strategies. SD modeling enables this type of analysis and communication in a value chain setting, thus providing a deeper understanding of the complex and dynamic nature of agricultural value chains and the interactions between markets, institutional coordination and governance, biophysical phenomena, and income. SD models provide a complementary toolkit to existing value chain methods to improve engagement with inclusive value chain development processes and to target scarce donor resources more effectively.

5. CONCLUSIONS

5.1 Overall empirical findings

This research exemplifies and confirms various opportunities and challenges for smallholders when participating in or entering higher value agri-food chains in a changing food system. The articles in this thesis complement each other, as illustrated in the article summaries, by focusing on different aspects important to smallholder inclusion in value chains, and by using different approaches to systems thinking and modeling to address inclusive value chain development. The Tanzanian case study presents an example of smallholder dairy goat farmers operating in local markets with possibilities of accessing larger urban markets, but who face several physical, economic, and institutional challenges when attempting to do so. This case study emphasizes the potential benefits of partnerships to overcome some of these challenges and improve the smallholder dairy goat farmer livelihoods. However, partnerships can also have unintended consequences on governance that may work to the detriment of smallholders. Acknowledging and appreciating the different feedbacks along the chain is critical in developing sustainable partnerships, and to achieve both economic and social goals. The extended accidental adversaries model and governance model presented in Article 1 reveal feedback mechanisms that need to be addressed and that are often not considered when the system as a whole is not taken into account.

In Nicaragua, dairy farmers actively participate in formal dairy value chains through cooperatives that have access to large national and international markets by supplying industrial processors. But to remain competitive and profitable alongside larger producers, and to open up opportunities for new entrants, there is a need to overcome challenges in the feed sector to improve both volumes and quality of milk. The Matiguás case primarily highlights the impacts of potential technical interventions in addressing these challenges, while modeling the value chain clearly illustrates the interactions between markets, coordination aspects, biophysical phenomena, and income. Paying attention to the roles that these feedbacks play in shaping the system is important when planning and implementing policy measures. Throughout the participatory model building process, the participants from the Matiguás dairy value chain acquired a better understanding of the complex and dynamic nature of the value chain, and how they perceive the chain differently.

The results from both case studies highlighted the need for addressing economic, institutional, ecological, and social challenges chain-wide, to successfully promote long-lasting inclusive value chain development, that results in improving smallholder livelihoods.

5.2 Theoretical and conceptual contributions

The four articles applied different methods of systems thinking and modeling to identify and test governance structures, and to upgrade strategies to improve smallholder farmer competitiveness to remain or increase their profitable participation in the dairy value chains. The articles therefore contribute in different ways to advancing the use of systems thinking and modeling in inclusive VCA and development. Based on the experience from this research, each of the four steps in VCA can benefit from the use of systems thinking and modeling. These contributions are summarized in Table 1.

When mapping a value chain, systems thinking and modeling captures the relations and interconnections between different nodes and actors in the value chain. When using a participatory approach, such as GMB, it is important to capture the complex system correctly through those who know the system the best, to collect necessary and updated information, and enhances the understanding among the VC stakeholders of the complex systems in the value chain. Stock and flow diagrams present a detailed visual representation and clearly show the complex interactions inherent in a value chain. The flows of products and services are clearly portrayed, as well as the actors actively involved in the chain. In a quantitative SFD, the number of actors, the amount, volume of, and possibly even the value of input, production, processing, and sale are incorporated. Importantly, the dynamics of these numbers are captured through feedback loops by the use of stocks, flows, and variables.

Value chain governance identifies the coordination mechanism and their rationale within the value chain. This in turn motivates the conditions for inclusion or exclusion of smallholders in the value chain, and is therefore crucial to analyze. When analyzing governance structures, the extended accidental adversaries model and governance model, can portray the activities and relations between different actors in the chain and how they are interconnected through different relational aspects such as power and trust. These feedbacks influence the collaboration or partnership according to different intended and unintended consequences of decisions made in value chains with multiple actors working towards their own objectives and a common overall goal. The two models provide valuable additions to the theory of value chain governance and partnerships. Governance can also be included in quantitative SFDs as decision parameters that guide the inflows and outflows of stocks.

Table 1: Summary of applications of systems thinking and participatory modeling to value chain analyses in the four articles of this thesis

Value chain analysis framework	Relation to article	Application of systems thinking and participatory modeling
1. Mapping the value chain	Articles 2,3, and 4	A qualitative SFD provides details of how the different nodes or subsystems in the value chain are interconnected and highlights dynamic relationships among them. Constructing an SD model using a participatory method, such as GMB, enhances the understanding among the value chain stakeholders of the complex systems in the value chain.
2. Analyzing governance structures	Articles 1 and 4	The extended accidental adversaries and governance model diagram focusing on partnership activities and governance aspects can contribute to increasing the success of value chain partnerships inclusive of smallholders by understanding important feedback issues in the chain. In the quantitative SFD, governance is incorporated through decision variables such as how much to supply when, where, and to whom, which influences implementation of interventions.
3. Identification (and testing) of opportunities for upgrading	Articles 2, 3, and 4	In qualitative SFDs, the identification of the interrelations and feedbacks between the different nodes and subsystems in a value chain can identify challenges and potential solutions. A quantitative stock and flow model allows testing of different policies and value chain interventions. Participatory modeling leads to a more relevant, validated model, increases the commitment to chosen strategies, and improves the participants' understanding of the value chain.
4. Assessing distribution of benefits	Article 4	In a quantitative SFD, both intended and unintended benefits with the chosen interventions and policies can be tested in the short, medium and long run. This includes the distribution of benefits, such as the effects on smallholders.

Source: Developed by the author

SD models not only identify upgrading strategies, but also enable simulation and testing of different upgrading strategies and specific value chain interventions. This is perhaps the most beneficial addition of applying systems thinking and modeling to VCA. Systems thinking and modeling illustrate the overall value chain system as portrayed through a conceptual model or value chain map, but also provide details on the specifics of the system by breaking it into interacting subsystems or modules. These modules can combine system behavior that merges different disciplines such as animal and crop science, and economics and marketing. The interdisciplinary approach enables more holistic testing of different policies and interventions that focus on upgrading of products and processes, or on functional upgrading. Participatory processes accentuate this type of analysis. By actively being part of the entire modeling process, GMB participants developed a deeper understanding of the value chain and its dynamic nature, which helps them to acknowledge and incorporate implications of decisions they make, as well as implications of interventions to the system.

Value chain upgrading seeks to achieve a variety of development outcomes, such as increasing the competitiveness and income of smallholders, which contributes to livelihoods improvement. Correspondingly, the distribution of benefits also needs to be assessed by looking at who wins and who loses. If an intervention increases the production of milk, but at the cost of smallholder income (from rising input costs for example), it cannot be considered a successful intervention if aiming for inclusive value chain development. Moreover, there could be different benefits that manifest in the long term that are not apparent in the short term.

Unlike traditional VCA, SD models can provide useful insights on the consequences and potential tradeoffs that chain-oriented policies could have. SD models empirically test and quantify the potential effects of value chain interventions *ex-ante* and provide information about intended and unintended consequences, which is indispensable knowledge for decision-makers. Equally important is the information provided on short-, medium-, and long-term effects. This provides valuable information for policy-makers and donors when making decisions about which policies and value chain interventions to promote, prioritize, or invest in when aiming for inclusive value chain development.

The case study approach provided a good framework for testing the use of SD modeling in VCA. It also provided a good approach to further build this theoretical and methodological approach to achieve inclusive value chain development in a manner that improves smallholder livelihoods. The richness and heterogeneity of the two case studies enabled me to use and test different SD approaches, which has resulted in more understanding and learning than would have been possible if applied to only one case.

5.3 Methodological contribution

Valuable methodological experiences were made during this research. For example, detailed scripts for the five GMB sessions were developed, which can provide useful guidance for other participatory modeling projects focusing on value chains in developing countries. The second article also provided details about the entire process from beginning to the end, including an assessment of challenges. This can further contribute to the work initiated by Vennix (1996), Hovmand (2014), and others who have added to developing the GMB methodology by providing new and updated information about experiences of using GMB in the field. Based on this research experience, a generic procedure of how to conduct a GMB process in a value chain context in developing countries can be developed. This would include scripts, materials, time, and people needed, as well as guides for participant selection. This would take existing information about GMB one step further. Even outside the value chain space, this research contributes insights that can be applied in other participatory model building projects and also beyond the developing country context.

The structure of the Matiguás dairy value chain model can also provide a good starting point for other applications of SD modeling to dairy value chains elsewhere. This can make the process less time-consuming and make it easier to introduce SD concepts. As the Nicaraguan model is hosted online, the logic of using a participatory systems thinking approach to understanding complex and dynamic value chain problems can be illustrated for a variety of users, including current value chain stakeholders, students, and scholars. Few models are available online today, and none, to my knowledge, with the developing country context and value chain focus.

The extended accidental adversaries model and the governance model, as presented in Article 1, provide a good foundation for identifying and discussing the dynamics of governance and how different governance mechanisms impact on value chain upgrading, chain participation, and partnerships, specifically addressing smallholder inclusion. The models can be used by practitioners to make governance mechanisms explicit, which is an important contribution to what many stakeholders in the value chain, as well as analysts, consider a vague and abstract concept and therefore struggle to understand. The models can support identification of better governance structures that ensure that partnerships survive individual short-term fluctuations as well as long-term market trends. The two models could benefit from further testing in the field, and from development into a quantitative model that can be used to simulate alternative scenarios over different time frames. This would explicitly model the evolution of governance structures and clearly show the implications of these dynamics over time.

5.4 Policy implications

Policy-makers and others intervening in value chains have many options for how to support smallholder participation in higher value agri-food marketing chains. Their challenge is to understand the complex and dynamic nature of the value chain and to have sufficient information to make good decisions. A participatory SD approach addresses a major analytical shortcoming of VCA, which is the most commonly used framework for the analysis of value chain development. As a complementary process to the rigorous, structured, yet flexible framework of VCA, a combination of systems thinking and participatory modeling goes deeper into the systems that drive value chains. It enables testing and prioritization of different policies and interventions, and of their impact on smallholders and other actors in the chain over different time scales. By using SD modeling, it is also possible to quantitatively assess economic, social, and environmental goals in VCA. This is important for donors in assessing their returns on investment. The empirical results support a current discourse within agricultural development, which states the importance of combining technological, institutional, and social interventions throughout the value chain, and to move beyond solely focusing on productivity enhancing interventions, to be successful (Devaux et al. 2016).

Participatory SD modeling therefore offers valuable information that policy-makers, donors, and others intervening in value chains can prioritize, to make smarter decisions and better contribute to inclusive value chain development. It forces decision-makers, both within and external to the value chain, to think in the longer term and tackle root causes rather than symptoms. SD models can be disseminated to donors, policy-makers and value chain actors by using a storytelling function in the modeling program, as well as running live simulations of different scenarios. Although the focus in this research has been on the dairy value chain, the approach can easily be applied to other agricultural or non-agricultural value chains.

5.5 Challenges and weaknesses with the approach

Despite the usefulness of this approach, applying systems thinking and participatory modeling to VCA does not come without challenges. This approach requires expert modelers and commitment by selected value chain stakeholders to actively participate in the GMB process. Constructing an SD value chain model without a participatory model building process might not accomplish consensus-based decision-making, team learning, commitment to chosen strategy, and sustainability of interventions. Thus, the design of a good participatory model building process is critical to ensure success. Addressing dynamic problems in value chains is challenging, and often fails, which can justify the use of this time- and resource-demanding approach. In comparison to surveys, however, which are also time- and resource-consuming methods, participatory SD modeling provides additional benefits that would be difficult to achieve otherwise.

SD models are based on aggregated data, whether focused on a municipality such as the Matiguás case, or on a regional, or even national level. This type of meso or macro VCA typically focuses on smallholders as one group, rather than on the heterogeneous group that they in fact are. In the Matiguás case, the focus was on small- and medium-sized farmers, leaving larger-scale farmers out of the model. Moreover, there was no differentiation between male and female producers, or those with different asset bases or differences in infrastructure, social capital, or even education level. It is possible to develop typologies of actors (by household type, location, or gender), or to represent different gender roles with different variables. However, this complicates the participatory model building process, and ultimately is a decision that needs to be made based on goals and requirements. In this sense, a weakness of SD modeling is that individual-level behavior is not directly captured, which would necessitate a more micro-level approach such as agent-based modeling. However, SD still represents a useful space, particularly at a value chain level, between more aggregate sector-level modeling found in the economics literature and household-level micro-econometric or agent-based approaches.

Another challenge is that SD modeling most often uses expensive computer software, which is difficult to access for value chain stakeholders, especially in developing countries. Without access to the modeling software, iThink and Stella Architect in this case, it is difficult for stakeholders to fully use the model unless it is hosted online. Even in these cases, without the software itself, it is not possible to change the model structure or to run other simulations with small alterations. This can be avoided if using a free software such as Insight Maker[6]. Further use and testing of Insight Maker and other free software programs is necessary, to find out if they satisfactorily fulfill the requirements of this type of modeling.

Limited retrospective analysis has been completed based on the findings from this study, and as such it is difficult to know whether its goals or effectiveness over time can be sustained. Little is known about how correct or useful or not the information provided by the analysis was in shaping decision-making. There is, hence, a need for long term, or follow-up projects that specifically analyses intervention and model-building effectiveness, and which can document and analyze long term impacts in comparison to the predicted model results.

5.6 Future possibilities

Continuing the development, testing, and use of both qualitative and quantitative applications of SD modeling for developing country value chains would contribute to improving the process of inclusive value chain development, and improve smallholder livelihoods. Systems thinking and participatory modeling should therefore become a part of the VCA approach. Additional applications and case studies, which go beyond dairy value chains, are needed to achieve this. The SD models used and developed during this research can also be further developed and applied elsewhere. For example, the Mgeta dairy value chain could benefit from both a quantitative governance model application, as well as a participatory SD model building process to assess the potential effects of different upgrading strategies and associated interventions. The quantitative SD model presented in Article 4 could be further developed to be able to evaluate costs and benefits in monetary

[6] Available at https://insightmaker.com/

values of interventions. One would then be able to answer questions such as: “What can we achieve if we have X amount of money to invest in this specific value chain?” An answer could be found to the query: “How much money is required to implement this policy and associated interventions?” The quantitative model of the Matiguás dairy value chain would only need some additional structure and data to achieve this. Unfortunately, this was beyond the time frame of the current research.

The combined experiences and outputs of this research can form the backbone of a guide and manual on how to use different systems thinking and modeling techniques in the different steps of VCA using participatory methods. This would support the incorporation of systems thinking and applications in VCA and make it more accessible to researchers, practitioners, policy-makers, and donors who aim for inclusive value chain development. A guide should focus on how to identify which type of model to use when, how to design and implement a participatory model building process, how to evaluate both the model and the process, and how to use and communicate results from SD models applied in inclusive VCA and development. This would add to the numerous, but similar guides to VCA. A manual about systems thinking and participatory value chain modeling would provide an interdisciplinary, systematic, and participatory framework to inclusive value chain development. The approach builds on the strengths of conventional VCA and addresses its weaknesses and results in providing clear advice on which strategies have the greatest potential to promote inclusion of smallholders or other vulnerable social groups into value chains, by strengthening their competitiveness, and at the same time resulting in increased income and overall livelihood improvement.

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PART TWO: Compilation of Papers

ARTICLE 1

A systems perspective on partnerships and governance in smallholder agricultural value chains

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Abstract

Purpose: Partnerships can be an attractive solution for smallholder farmers to upgrade their positions in agricultural value chains. However, the inclusion of new actors requires reconciling different interests and governance structures. This paper uses a systems based approach to analyze the effects of changing governance relationships in agricultural value chains that are mediated through partnerships.

Design/methodology/approach: This paper utilizes a systems thinking approach to better understand the dynamics of governance of value chain partnerships. The Mgeta goat milk value chain in Tanzania is used as a case study.

Findings: The systems thinking approach to partnerships and governance offers insights into the intended and unintended consequences of decisions made in a complex and dynamic value chain system with multiple actors working towards both their own objectives and a common overall goal.

Research limitations/implications: Owing to the novelty of the approach to analyze partnerships and governance in value chains, the next step is to empirically test the framework with the key partners and enablers in a value chain. The framework can be implemented quantitatively to allow assessment of different partnerships and related governance typologies over time, and to empirically test the impacts of changing leverage points.

Managerial or Policy implications: By addressing the means by which partnerships affect value chain governance, and their effects on smallholder farmers, the framework can help donors and policy-makers intervene more successfully in pro-poor value chains.

Originality/value: This article presents a useful and novel systems approach to analyzing the dynamic nature of value chain governance and the impact this has on value chain upgrading, chain participation, and collaboration.

Key words: Governance; value chain; systems thinking; partnerships; accidental adversaries; smallholders; dairy; Tanzania.

1. Introduction

Smallholder farmers face numerous challenges when participating in and upgrading their position in value chains (CFS 2015). The quantity of resources that farmers have – referred to as their asset base – is an important factor to bear in mind when creating and sustaining competitive value chains. Unfortunately, smallholders often face constraints in some or all of the human, social, financial, natural, and institutional assets that are needed to succeed (Lie et al. 2012). Partnerships between businesses, non-governmental organizations (NGOs), public sector agencies, and farmers are often promulgated to facilitate the inclusion of smallholders in value chain development (Bitzer & van Wijk 2011; IFAD 2013).

Narrod et al. (2009) highlight the role of public–private partnerships as a means of overcoming the market failures associated with smallholder exclusion from high-value chains by leveraging the strengths of public and private entities to enhance the capacity and asset base of smallholders. Such partnerships can be seen as an attractive solution, since businesses can offer access to larger markets and improve smallholder compliance with quality and volumes sold, while public sector actors can backstop the perceived risks associated with smallholder participation (Narrod et al. 2009; Poulton & Macartney 2012). Public sector and civil society groups also play important roles in providing capabilities to smallholder farmers to better meet the demands from the private sector, and to avoid asymmetric power relations (IFAD 2013). Partnerships can arrest the negative effects that arise from limited smallholder asset bases. Smallholders obtain access to new markets and technologies, reduce transaction costs, and increase demand for their products, which further enhances their motivation to re-invest, leading to increased income and improved livelihoods (Altenburg 2006; Bitzer & van Wijk 2011).

However, partnering with either the public or the private sector is not always a straightforward matter. In particular, the inclusion of new actors requires reconciling different interests and organizational structures (Altenburg 2006). New value chain partnerships further change the conditions for participation in and coordination of the chain – in other words, value chain governance (Gereffi et al. 2005). When smallholder farmers move from local market arrangements or coordination through farmer organizations, to partnering with the private sector or in a public–private partnership, governance relations can become more captive in nature, leading to greater asymmetries in power relationships (e.g. see Lang 2003; Rüsch et al.

2014; Sivramkrishna & Jyotishi 2008). This can affect the ability of farmers, or subsets of farmers, to influence their position in the value chain, or in determining which farmers can participate (CFS 2015; Ros-Tonen et al. 2015). It is therefore important to carefully consider changes in value chain governance and the intended and unintended effects that can arise when upgrading agricultural value chains through new partnerships.

There are few frameworks in the development literature that analyze the dynamic nature of governance structures and their consequences for value chains. Gereffi et al. (2005) provide important formative work on defining typologies of governance, further discussed and developed by several others (e.g. see Bair 2009; Gereffi & Lee 2014; Gibbon et al. 2008). Ponte and Sturgeon (2014) propose a modular approach to governance, focusing on the micro, meso, and macro level of governance in the value chain. Pietrobelli and Saliola (2008) offer a quantitative way of measuring governance and firm productivity and the impact on supplier performance through econometric tests, while others offer various conceptual frameworks on governance (e.g. Lange et al. 2013; Ros-Tonen et al. 2015). However, none of these enable analysis of the dynamic nature of value chain governance, nor of the impact this has on upgrading, chain participation, and collaboration.

The systems thinking perspective (e.g. see Forrester 1971; Senge et al. 1994; Sterman 2000; Warren 2008) provides both a philosophical and a methodological approach for understanding the behavior of complex dynamic systems. Value chains are clear examples of such systems and have been investigated using system dynamics modeling to understand the causes and control of problematic behaviors in value chains (e.g. Lie & Rich 2016; Rich et al. 2011). A system dynamics model maps the flows, processes, decision rules, and relationships between actors that operate within a complex system (Sterman 2000).

In agricultural value chains, the movement to a new type of governance fostered by a partnership, introduces additional complexities. A systems perspective highlights important intended and unintended effects on different parties in a partnership when the governance structure in the value chain changes. This is important when entering into new partnerships or improving existing ones, and can support policy-makers and donors to successfully intervene in pro-poor value chains.

The objectives of this paper are to examine (i) what role governance play in developing and sustaining value chain partnerships, (ii) how new value chain partnerships affect the dynamics of value chain governance, and (iii) how changes in value chain governance affect smallholder inclusion in value chains. This is achieved by using a systems based approach to analyze the effects of changing governance relationships in agricultural value chains that are mediated through partnerships. This is exemplified in practice by applying it to the case of the smallholder goat milk value chain in Mgeta, Tanzania.

The Mgeta goat milk value chain offers a typical example of smallholder farmers with a limited asset base struggling to reach larger markets. Some value chain upgrading has taken place through collective action and with strategic public sector support. However, this group has not yet managed to penetrate larger urban markets, which limits the potential of small-scale dairy farmers to improve their livelihoods. At the same time, opportunities currently exist to partner with a commercial dairy, which could increase milk demand, incorporate more farmers, and stabilize incomes. While partnering with the private sector provides access to newer and more diverse markets, it comes at the price of losing control of, and the benefits from, higher value products. Moreover, the nature of the partnership determines how the governance structure changes and evolves over time and, consequently, how farmers may benefit or lose from value chain participation. The approach in this paper provides guidance for decision-makers on how best to support smallholder value chains with these dynamics.

2. Theoretical frameworks

2.1 Partnership

Agricultural value chains are dynamic and complex social and economic systems comprised of many nodes and actors. Agricultural products are perishable and often need to be transported over long distances to reach consumers. Additionally, some undergo further processing if not sold and consumed fresh. The increasing demand for specific and high quality agricultural products increases the need to coordinate the chain. Coordination refers both to vertical relations between actors in the chain, and also to horizontal relations between actors within one node. Horizontal coordination is sometimes seen as a precondition in agricultural value chains to be able to reach scale and improve negotiation power (Bijman et al. 2011; IFAD 2013; Vellema 2016). Motives to coordinate include the reduction of transaction costs and risks, enhancements in the ability to innovate and differentiate, more efficient exchange of information, and improved market position. Challenges with coordination include high demand on capital and reduced flexibility (Bijman et al. 2011; Ziggers & Trienekens 1999).

Partnerships between actors in agricultural value chains can be defined simply as "voluntary and collaborative arrangements" (Bitzer & van Wijk 2011: 221) between two or more actors. Such actors are complementary to each other based on their comparative advantage resulting in a division of roles and responsibilities. Partnerships allow actors to achieve goals that they cannot reach on their own, which improves motivation to participate. A partnership aims to solve a specific problem, such as difficulties with market access, food losses, or poor food quality in agricultural value chains, which requires identification of needs, inputs, and resources (Clancy & Narayanaswamy 2016). Partnerships can vary from loose networks and strategic alliances to contracted agreements on specific deliverables (Peterson et al. 2001). Smallholder farmers often collaborate among themselves, with the public sector, with NGOs, with the private sector, or in any combination of these options.

To avoid unbalanced partnerships in value chains that lead to clear winners and losers, there are specific relational or governance aspects that are important to consider. Consolidating different interests into a *shared vision* and *time line* is a crucial starting point. This lays the foundation for shared *commitment* and *ownership* between partners who have clear division of roles and responsibilities based on comparative advantages. This further leads to *mutuality in risk sharing* as well as *shared accountability for outcomes and results*. *Power symmetry* is also central, and a focus on building *trust* through *consensus-based decision-making*, *information sharing*, and *transparency* contributes significantly to successful outcomes (Altenburg 2006; Bitzer & van Wijk 2011; Brinkerhoff & Brinkerhoff 2011).

2.2. Value chain governance

Governance in value chains highlights the relationships between the different actors and the coordination mechanisms that exist within a value chain. Governance can be defined as "how certain actors set, measure and enforce the parameters under which others in the chain operate" (Bolwig et al. 2010: 176). The governance structure in value chains specifies what type of product is needed, by whom, how much, when and how it should be produced, and at what price. This is a result of strategies and decision-making taken by particular actors. Governance is typically constructed by the chain leader who coordinates the chain; this depends on whether the chain is mainly producer-driven or buyer-driven (Gibbon et al. 2008). Owing to perishability, seasonal characteristics, and quality/food safety standards, agricultural value chains often need to be more tightly coordinated, with different mechanisms used at different value chain nodes.

Value chain governance has been discussed and developed over the past 20 years (e.g. see Gereffi et al. 2005; Gereffi & Lee 2014; Gibbon et al. 2008; Humphrey & Schmitz 2001; Kaplinsky & Morris 2001; Ponte & Sturgeon 2014). However, the five governance typologies developed by Gereffi et al. (2005) are still widely used, and range from classic markets to vertically integrated firms (hierarchies). They build on some of the classic academic contributions in industrial organization which originally highlighted the motivations for relying on markets versus hierarchies (Coase 1937; Stigler 1951). In-between classic markets and hierarchies are three hybrid forms of relationships: modular, relational and captive types of governance. They vary in degree of coordination, primarily based on the degree of asset specificity, but also on the complexity of transaction, and ability to codify transactions (Gereffi et al. 2005). Wever et al. (2012) refine this further by looking at the dynamics of how governance structures can evolve, specifically highlighting the importance of considering both supply-side and demand-side transaction risks when making contract decisions. Peterson et al. (2001) focus on strategic decisions such as the use of contracts, alliances, or vertical integration, where decisions are based on considerations such as the interest of the partners, the length of the relationship, and the degree of information sharing.

Governance is influenced by the existence of value chain partnerships and the partnership characteristics. Table 1 combines the five types of value chain governance and their characteristics based on differences in products, actors, actor characteristics, and partnership- and coordination characteristics, while focusing on smallholders in agricultural value chains. Table 1 highlights how the characteristics of governance relationships change when moving from a reliance on markets to more coordinated value chains. As governance mechanisms become more tightly organized, the greater the need for closer coordination among the partners. However, the more coordinated the chain, the greater the likelihood of the chain being controlled by the chain leaders, leading to greater asymmetries in power among chain actors. At the same time, partnership programs often assume win-win situations and promote this without explicitly addressing potential areas of conflict that might compromise the partnership over time. Lead firms, such as commercial processors in agricultural value chains, often share interests with their suppliers regarding overall efficiency of the chain, but they have different interests with respect to negotiating and deciding on quality standards, prices, terms of payment, and contractual obligations (Altenburg 2006), as seen in table 1.

Table 1: Governance and partnership aspects in value chains

			Market	Modular	Relational	Captive	Hierarchy
	Partnership actors	Individual smallholders Producers association Public Private	X	 X X X	 X X X	X X X	 X
	Actor characteristics	Asset base smallholders	Medium	High	Medium/ High	Low	Low
Leverage points	Product characteristics	Price Volume Quality	Decided on the spot	Negotiated for each	Agreed among partners	Decided by chain leader	Internal control
	Partnership characteristics	Shared vision Length of relationship Degree of dependence Shared commitment and ownership	None One time None None	None Short Low Low	Yes Long High High	None Long High Low	None Long High None
	Coordination characteristics	Transparency and information sharing Consensus-based decision-making Degree of trust Power symmetry	Low Low Low High	Moderate Moderate High High	High High High High	Low Low Low Low	Low Low Low Low
	Degree of coordination	Low ←→ High					

Source: Developed by the authors based on Bitzer and van Wijk (2011); Gereffi et al. (2005); Peterson et al. (2001); Wever et al. (2012)

2.3 The systems thinking approach

The systems thinking perspective is an effective way to approach the dynamic relationships and governance effects associated with partnerships. An important challenge to decision-makers in complex and dynamic decision situations is to avoid adopting a linear, event-oriented perspective when confronting a problem. Complex systems such as agricultural value chains are comprised of numerous actors (smallholders and other stakeholders) who are engaged in activities that affect others in the chain, and which are affected by what other actors do. Every action triggers a reaction. This is called feedback and is defined as “the process wherein one component of the [system] initiates changes in other components, and those modifications lead to further changes in the component that set the process in motion” (McGarvey & Hannon 2004: 6). Ignoring the presence of multiple feedback relationships and time delays frequently leads to the systemic reactions of unintended consequences, counterintuitive behavior, and policy resistance (Sterman 2000). To avoid these generally undesirable outcomes, an understanding of the so-called “physics” of the system can be achieved by adopting a feedback-oriented perspective.

According to Sterman (1994), feedback relationships are classified as being either reinforcing (positive) relationships or self-correcting (negative, balancing). Growth processes are associated with positive feedback loops. For example, investing in vegetable planting increases the size of the harvest, which increases the farm income, which leads to more investment in vegetable planting in the future. This is an example of a reinforcing feedback loop, as illustrated in Figure 1. It is unrealistic to assume that growth will continue without constraints or other reactions. Good farm land is a scarce resource and will eventually be used up, limiting the growth of the farmer’s income. The limits on growth are the consequence of negative, or balancing, feedback loops. The dynamic interaction of these loops on key variables results in different forms of observed behavior. In this example, the positive feedback loop will generate exponential growth in the amount harvested until land becomes increasingly scarce. Over time, the process results in an S-shaped curve of harvest size. Ultimately, an equilibrium state will be achieved when the combined effects of the two loops are balanced (Sterman 2000).

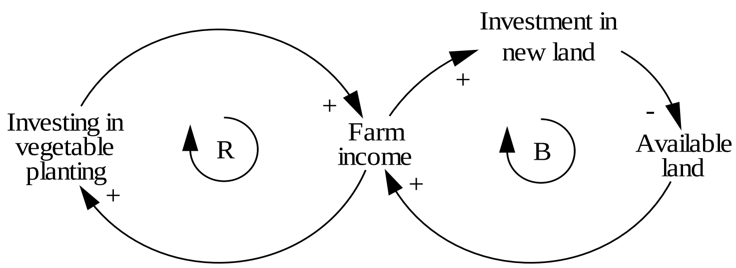

Figure 1: Illustration of reinforcing and balancing feedback loops.
Source: Modified from Sterman (2000: 14)

Action and reaction do not occur instantaneously. There are usually many time delays in a system that result from communication inefficiencies in organizational systems, which can constrain and delay the flow of information, or physical/biological characteristics in natural systems. The maturation time before vegetables are ready to harvest, is an example of the latter. This means that decisions are frequently taken on the basis of information that is delayed, or that actions are based on perceptions of a state of nature, which may be time-delayed and thus imperfectly reflect the actual state (Sterman 2000).

Despite the apparent obviousness of these observations, there are too many examples of cases where the decision-maker's perspective is based on a linear understanding of the problem (Sterman 1994). The unintended side effects of well-intentioned actions are often not considered, leading to dysfunctions in the system (Forrester 1971). Side effects, or unintended consequences, of one actor's actions in support of their local goals can obstruct the ability of another actor to achieve their local goals – all of this while there is agreement to work together in support of their common well-being (Senge et al. 1994). For example, a farmer who increases the amount of planted vegetable will require more water. If the water supply is limited and common to other farmers, then the farmer's increased consumption may make it impossible for others to achieve their objectives. The danger of relying on event-oriented thinking in a value chain is that it ignores the secondary consequences of one actor's activities to improve their condition on the other members of the chain. This mode of thinking explicitly ignores the many upstream and downstream connections between the value chain actors.

Figure 2 is a schematic of the dynamic nature of relationships between different actors in a generic agricultural value chain; for simplicity and exposition, the discussion is limited to three nodes in Figure 2, realizing that agricultural value chains typically have many more linkages. In the figure, it is assumed that there is a form of collaboration or partnership between smallholder producers, an association that collects products, and a commercial processor. Each actor is interconnected through the flow of products and influence on each other's decisions. The flow of products is, as discussed earlier, influenced by the governance structures of the chain as well as by individual and collective decisions that are illustrated by the circular arrow. Decisions are made individually within each node, but rarely without influence from collaborations or partnership with other actors in the chain, as well as influences from the enabling or external environment. When partnerships are established, collective decision rules will further influence individual-level decisions.

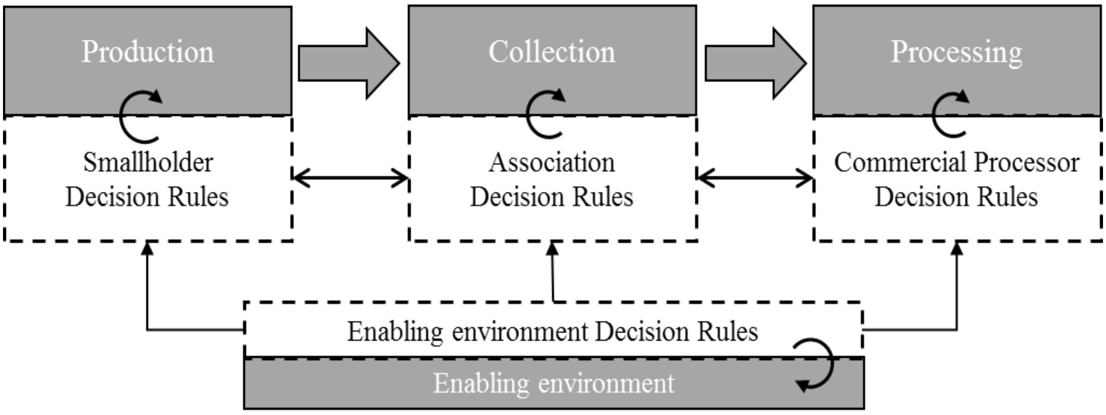

Figure 2: The dynamic system of an agricultural value chain

Source: Developed by the authors

3. The systems perspective on partnership and governance in value chains

3.1 Accidental adversaries between partners in value chains

Systems thinking research has uncovered a wide range of generic system structures, called system archetypes, that describe dynamic behaviors that result from the structural organization of systems (Senge et al. 1994). One of these, the "accidental adversaries" (AA) archetype (Kemeny 1994), stands out as a potential framework to analyze value chain partnership and the changes these induce in governance structures. The AA systems archetype is illustrated in Figure 3. The figure represents interactions between two partners, A and B. The outer reinforcing feedback loop (R1) illustrates the mutual beneficial activities of A and B that result in growth for both partners. Partner A's activity creates success for partner B, who is motivated to act in favor of A, which creates success for A. Concurrently, partners may also take independent actions to improve their own performance as seen in balancing loops B1 and B2. These actions are often the result of outside factors that are changing, such as changes in market conditions or policies, which force local agent action. The corrective actions of A and B to the changes in market conditions, for example, can unintentionally undermine the other's success. The growth cycle can then be turned into a vicious reinforcing loop (R2) that overwhelms the positive reinforcing loop (R1) of the partnership. Here, one corrective action has a negative impact on the other actor, who reacts in their own way, resulting in negative impact for the other partner (isee systems 2006; Kemeny 1994).

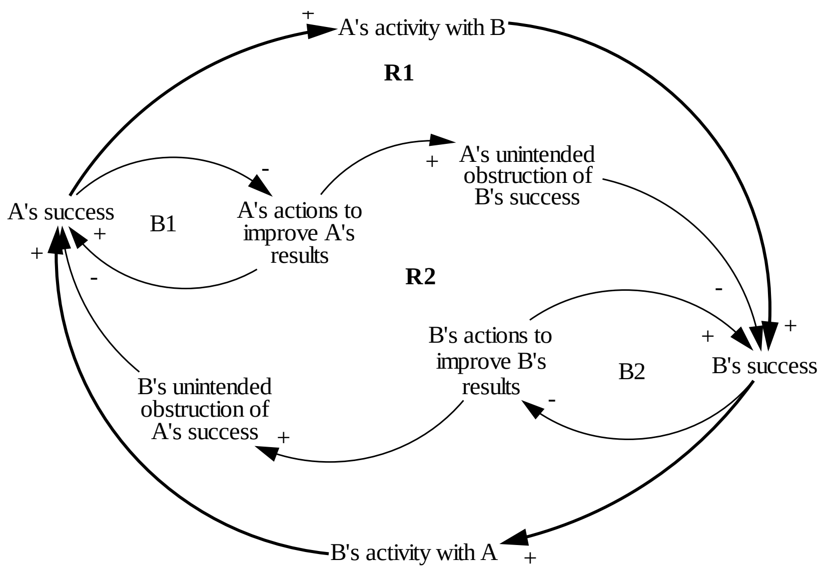

Figure 3: Accidental adversaries archetype. Source: Kemeny (1994: 146)

In a value chain with several actors, the AA archetype can be extended to include all relevant active and enabling actors. The following illustration in Figure 4 is of a very simple value chain with three active actors (A, B, and C) and external enablers. Active actors are those representing the different nodes in the value chain and the main partners who trigger feedback relations between each other. For example, Partner A could represent producers, Partner B collectors, traders, or processors, and Partner C processors or retailers. The enabling environment (denoted as “enablers” in Figure 4), is made up of policy-makers, NGOs, and service providers such as credit institutions. These actors can take specific actions that can alter partnerships, chain governance, or enable new partnerships.

Figure 4 illustrates the multiple decision-making processes between different actors in a value chain. The intended and unintended consequences of decisions have effects not only within the node where the decision is made, but also further upstream or downstream in the chain, which impacts not only on their own success, but also on the success of different partners and those downstream. Success can be indicated at an overall level focusing on how well the partnership is performing on the partnership characteristics presented earlier. In addition, the success of the partnership affects the success of the individual partners differently, which can be measured based on factors such as increased income or profit, increased participation of smallholders, or inclusion of women.

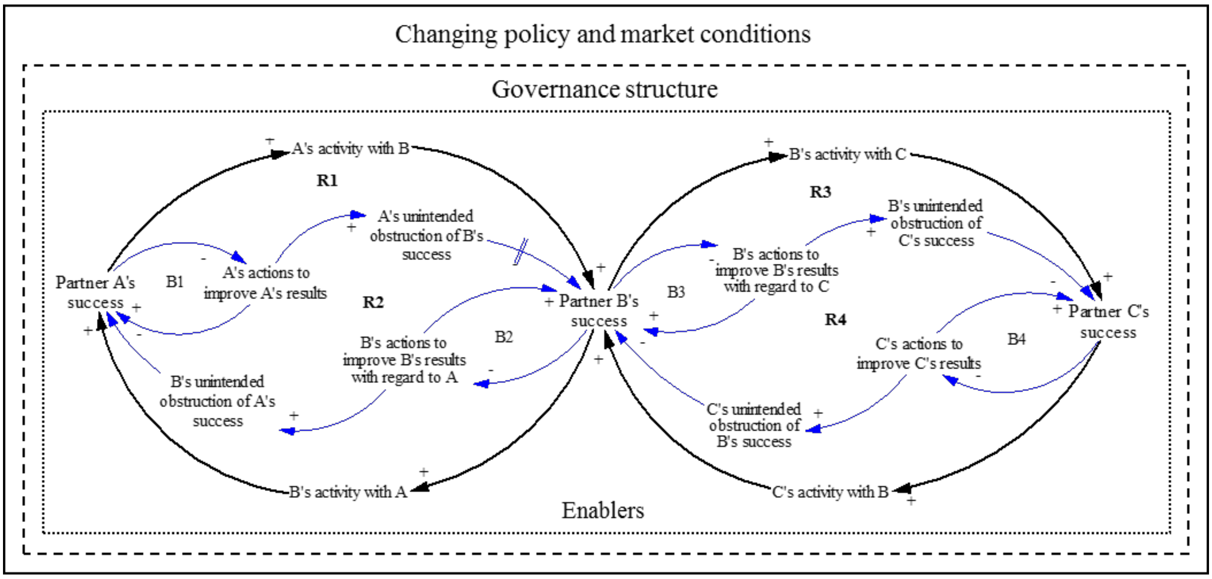

Figure 4: Extended accidental adversaries model for analyzing partnership and governance in value chains Source: Modified by the authors based on Kemeny (1994)

For partnerships to be effective, actors need to consider the implications of their local corrective actions on the other partner(s). It is important to have governance structures that ensure timely reactions between partners to avoid undesirable unintended consequences of their local actions. For example, how would they react to changes in price, volume, or regulations? Or how would a partner react to changes implemented to reach specific local goals? The governance structures in the value chain will reveal whether the partners continue to support each other's success, or whether local corrective actions negatively impact on partners, creating a vicious cycle.

3.2 Governance implications on partnerships in value chains

As argued through the paper, the success of a partnership structure, regardless of the configuration (see Table 1) is strongly affected by the governance structure. However, the AA model does not explicitly address this element, which is only identified in Figure 4 as encompassing the value creating activities. To remedy this, a governance model is presented that links the three value chain partners from Figure 4 into a governance structure in Figure 5.

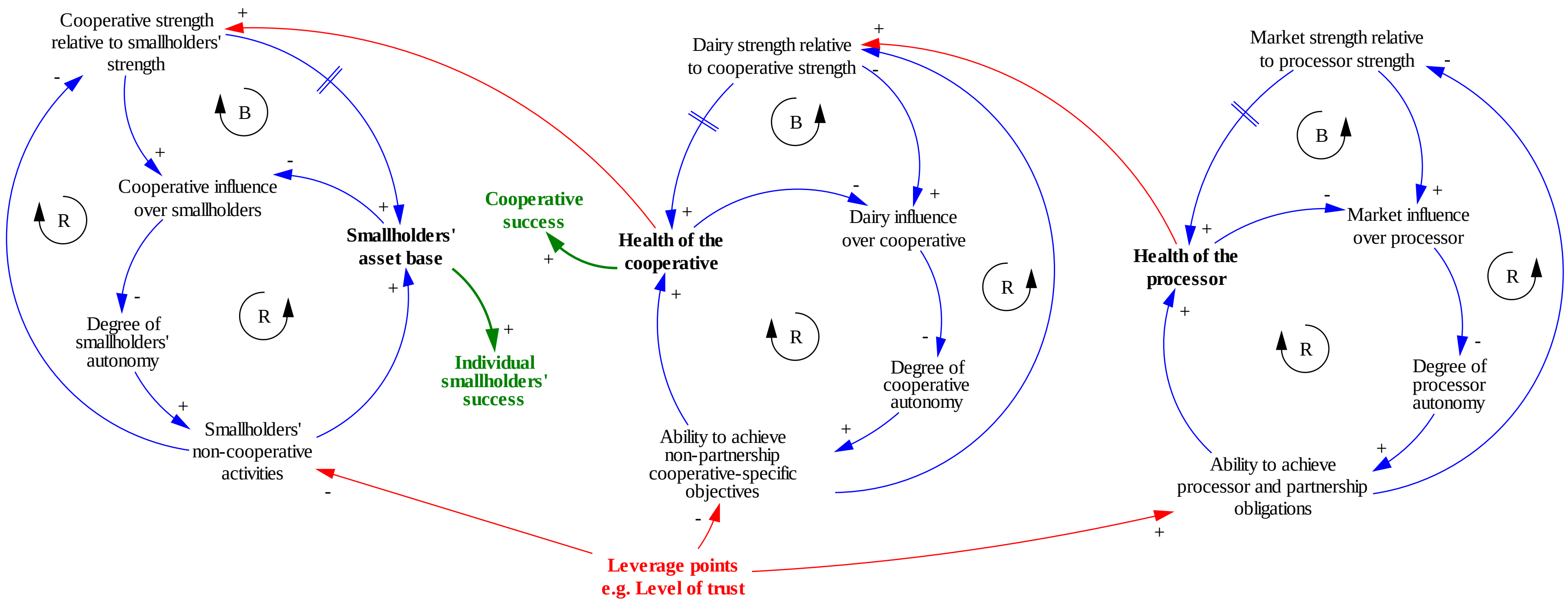

Figure 5: Systems model of value chain partnerships and governance. Source: Developed by the authors.

Figure 5 addresses some of the institutional aspects that underpin transactional dynamics in the value chain. Since power asymmetry is an important aspect of governance relationships, two variables are first defined, that capture the relative strength of one partner to another. In Figure 5, these variables are the relative strength of the cooperative to smallholders, and of the processors to the cooperative. These variables each have two effects. First, they have an economic effect that directly connects to success of partners as in the AA model (Figure 4). In a sense, this is the beneficial outcome in that the power of one partner over the other results in contributing to the weaker partner's ability to succeed. The second effect is that the relative strength variable describes the *influence* of the dominant partner over the weaker partner. This variable, in turn, affects the autonomy of the other partner. For smallholders, if the cooperative is relatively stronger than the smallholders, this can increase the smallholders' asset base, which is a desirable outcome. However, a strong cooperative will also be able to exert its influence over smallholders, thereby limiting smallholder autonomy with respect to conducting local actions that do not contribute directly to partnership success. The conundrum is that local activities also contribute to the asset base of smallholders – and it is this asset base which is the connecting variable between the governance structure and the AA value chain (Figure 4). A similar process applies to the cooperative (Partner B) and the processor (Partner C).

The level of trust and other leverage points such as common vision, shared commitment and ownership, transparency and information sharing (see Table 1 for additional leverage points) are important, if not crucial, aspects of successful partnership performance. These variables interact with the governance structure by influencing variables that represent the involvement of each partner with local activities that can distract them from the partnership objectives. Building relations that ensure continuous and good collaboration through communication, transparency, and trust are important aspects of the partnership. With these elements in place, partners will be in a better position to anticipate unintended consequences before making decisions with potentially negative impacts on the other actors in the value chain (isee systems 2006; Kemeny 1994).

4. Materials and methods

Mgeta, a group of mountain villages, lies in the Morogoro region of Tanzania. This paper builds on fieldwork conducted in Mgeta in 2010 and 2011 (Lie et al. 2012), but is primarily based on fieldwork from December 2013 to June 2014, and January 2015. Data is specifically taken from

12 focus group discussions with male and female milk suppliers in four different villages, two focus group discussions, and attendance in 10 meetings with the association leadership and in two general association meetings. Discussions focused on access to resources, relations with other stakeholders in the chain, and development of and decision-making in the goat milk value chain. Thirteen semi-structured key stakeholder interviews were conducted with the private dairy in Morogoro, extension workers, village leaders, and with others with extensive knowledge about the goat milk value chain. The group discussions and interviews were backed up by records from the association and observations of market promotions, and of day-to-day operations in Mgeta.

5. Systems thinking and the Mgeta goat milk value chain

5.1 Partners in the Mgeta goat milk value chain

Goat milk has been produced in Mgeta since the beginning of the 1990s. Smallholder dairy goat farmers have evolved from being individual farmers operating autonomously in the marketplace, to working collectively to collect and process milk into goat yogurt. This was made possible by resource pooling through Twawose (a dairy goat farmers association), and strategic public support from a university-led research project primarily focusing on increasing milk productivity. The large increase in dairy goats, reaching about 400 dairy goat owners and 2000 animals in 2014, has led to significant milk surpluses and consequently to opportunities to add value through developing new markets for the milk.

Despite the availability of excess milk, the association has struggled with coordinating the collection of milk to penetrate larger markets. The smallholders are becoming dissatisfied with their association. One reason for this is that there are approximately 500 to 1000 liters of goat milk produced in Mgeta every day, but only a small percentage of this is collected. The association only has 63 members. The association lacks the business skills to develop a marketing plan, minimize risks, and attract investment, all of which are central to expanding a business. Low education levels, limited access to information, and poor roads and power infrastructure are additional factors contributing to the low penetration rate into larger markets.

In response to the failure of capturing larger markets by the association, the opportunity of partnering with Shambani Graduates Ltd. (a private dairy) is being explored (Msalya et al. 2016). Shambani is a dairy based in Morogoro town about 50 kilometers from Mgeta. They have a processing capacity of 2500 liters per day, with the goal of increasing to 4000 liters. They source cow milk mainly from small-scale farmers and Masaai pastoralists up to 90 kilometers away. Processing goat milk could be an opportunity for Shambani to position itself with a unique product in the increasingly competitive dairy sector in Tanzania.

The development of the Mgeta goat milk value chain presents a multi-leveled, dynamic situation where the governance structure set the stage for participation and conditions of participation. The actions of one stakeholder, in support of their individual objectives, will interact with other stakeholder interests and possibly make it difficult for them to achieve their own goals. Thus, coordination is essential for development. The different actors in the Mgeta goat milk value chain have their own objectives and activities, and there are advantages and challenges associated with collaborating with others, which Table 2 highlights.

Based on current active and potential partners, many scenarios of value chain partnerships with different types of governance structures can be discussed using the systems approach. The baseline situation is a market-based system where farmers operate autonomously in the local marketplace. This will at all times exist alongside other systems and will not be discussed here since the focus is on value added chains and partnerships. One scenario is the current relational system where the association controls the value adding activities. Another scenario is an addition to the first, where the dairy is added as a partner to the association. Each scenario will be discussed using the two systems approach models: the AA model and the governance model, as presented previously.

Table 2: Characterizing partnership actors in the Mgeta goat milk value chain

	Actors	Metrics of success	Activities	Advantages	Challenges
Active partners	A. Individual smallholder dairy goat farmers (400–500)	Higher income from milk production, number of smallholders by gender that are included in the value added chain	Produce milk (500–1000 liters/day), breed goats, grow fodder	Independence and autonomy, freedom of choice	Limited access to resources: goats, land, financing, learning, market, technology
	B. Twawose, association of smallholder dairy goat farmers (63 members)	Profitable operations, inclusion of smallholders in the value added chain, increased income of smallholders, meeting demand for milk	Collect milk, run input supply shop, process (and sell) milk and yogurt (30–100 liters up to four times a week)	Improved asset base through pooling of resources among members, negotiating strength, benefits of coordinated action	Trust among members, effects of coordination, transparency, political game playing
Potential partner	C. Private sector partner – Commercial dairy	Increased profit, stable supply of quality products, market share	Collect bulked milk (500–1000 liters/goat milk), process milk, sell dairy products	Market access, predictability in demand, technical knowledge, financial resources	Assuring quality and quantity of supply, shared vision, power symmetry, trust, effects of coordination, transparency, political game playing
Enabling partner	D. Public sector partner – Agricultural university	Sector development, food security, poverty reduction	Capacity building for farmers, out-scaling of dairy goat keeping, knowledge and research in key areas	Strategic support to increase milk productivity focusing on breeding, feeding and goat management practices	Time constraints, one-dimensional, trust, effects of coordination, transparency and openness, political game playing

Source: Developed by the authors

5.2 Partnership through the dairy goat association

The Mgeta goat milk value chain has gone from spot market governance, where price is the main driving force, to a chain driven by relational governance where the smallholder producers themselves, through their association Twawose, process and sell drinking yogurt. In the AA model in Figure 6, the partnership can be illustrated by highlighting the main activities of smallholders supplying milk to the association and the association offering services such as collecting milk, input-supplies and veterinary advice (R1). These activities are a reinforcing feedback loop leading to success for the partners. Strategic support from the university facilitating training for dairy goat owners in breeding, feeding, and general goat management was essential in producing excess milk for processing. Additionally, the university supported the establishment of the farmers association and trained members in milk collection and processing.

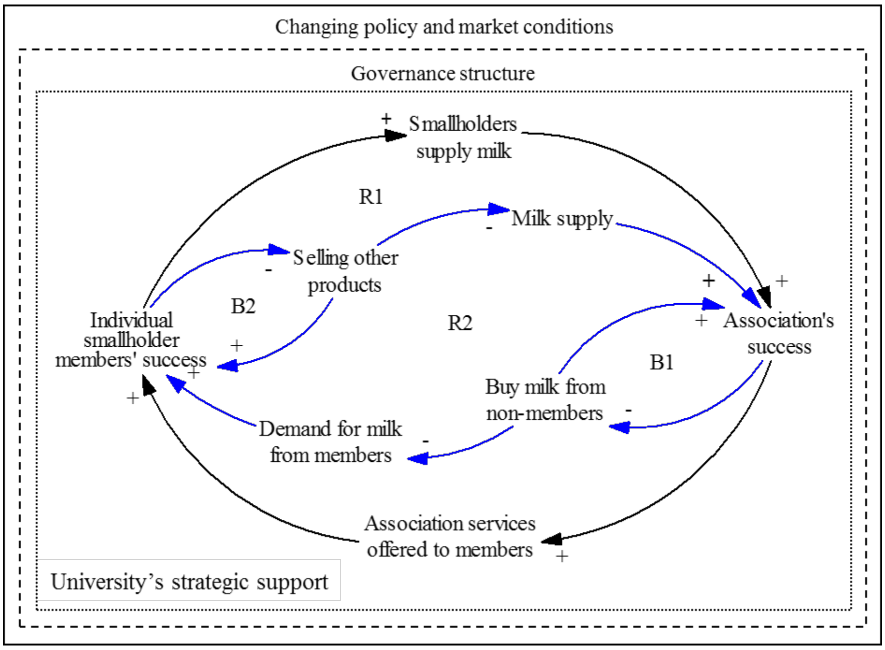

Figure 6: Accidental adversaries model illustrating implications of decisions made in the Mgeta smallholders' collective

Source: Developed by the authors

However, an analysis of the value chain shows that limited consideration has been made by the active and the enabling partners, of the possible unintended consequences of decisions made regarding the coordination of the horizontal partnership, which has had negative implications on the coordination of the value chain itself. Well-intended decisions made by the association leadership have had unrecognized, unintended consequences. For example, when the demand for milk was low, decisions varied on who could supply milk, by trying out different procedures. In a given week, association members in different villages could deliver milk on different days to limit the amount from each village, while in the next week, they limited the total amount from all villages. On the other hand, when demand suddenly increased, non-members were allowed to supply in order to meet demand, which resulted in activating balancing feedback loop B2 in Figure 6. These coordination decisions were made in good faith but only benefited some smallholders, and also did not contribute to reaching the full potential of goat milk processing and sale.

The decisions were taken with a short time perspective that did not consider the possibility of long-term unintended consequences. The result was minimal trust between the farmers and the association leadership as a consequence of low levels of consensus-based decision-making, limited transparency in plans and activities, and poor communication. Low levels of trust can lead to smallholders focusing on non-cooperative activities such as switching sales outlets by selling to neighbors or local restaurants (B2). If low levels of trust persist over time, this can lead to smallholders reducing the size of the goat herd and focusing more on selling other products such as vegetables (B2). These local actions (B1 and B2) lead to an AA-type of situation and a negative reinforcing feedback loop (R2) that results in limited success for both the smallholders and the association as a whole.

Using the governance model seen in Figure 7, we can see the implications of a weak partnership between farmers through the association. A weak association reduces the association's relative strength to that of smallholders, and subsequently their influence over smallholders, resulting in smallholders favoring activities outside those with the association. This will influence the smallholders' asset base (R3) and further reduce the association's strength relative to smallholders (R4). A similar story can be demonstrated between the power of the dairy relative to the association's strength (B4). Poor health of the association and higher market strength leads to reinforcing feedback loops (R5 and R6), which further increases the strength of the market and reduces the ability of the association to achieve the partnership's objectives.

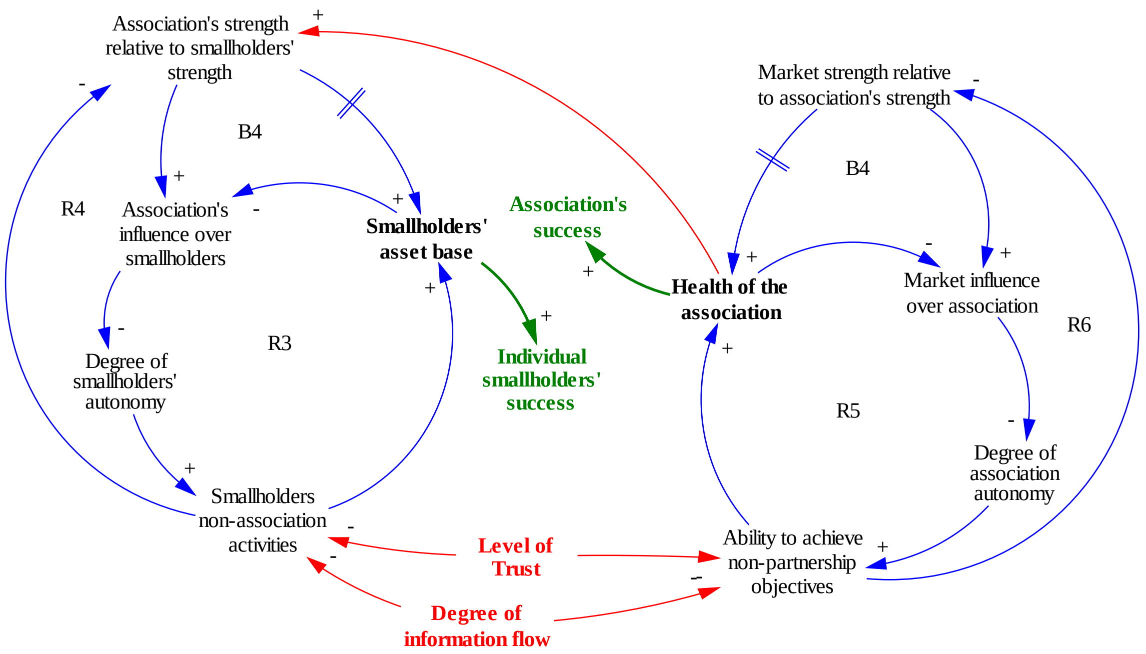

Figure 7: Governance model of partnership among smallholders through an association
Source: Developed by the authors

Group discussions with suppliers and the association leadership identified aspects such as communication, trust, transparency, sharing skills and experience, commitment, and accountability as important for a successful partnership. These aspects were rated as poor among surveyed actors, and the aspects themselves and their feedback had not been considered. Had the farmer collective considered these aspects and spent time on building stronger relations, the coordination effort could have resulted in different outcomes. At the same time, there are short-term transaction costs in building relationships, which could be mitigated over time but which are not realized *ex-ante* by actors. Both the suppliers and the association leadership identified improved communication as a key leverage point to improve the partnership. By applying the leverage points of trust building and improving information flows (see Figure 7) about challenges and possible solutions as well as improving consensus-based decision-making, the unintended negative consequences could have been avoided. Both smallholders and the association might then make local decisions that benefit the other actor instead of causing unintentional negative consequences. Both the smallholders and the association could also consider accepting higher short-term transaction costs, given greater confidence that the partnership is working towards the same vision, with agreed-upon strategies.

Despite the collective action and strategic support of the smallholder farmers in Mgeta, there has been no success in accessing larger markets. The market is still relatively stronger than the association and the association fails to meet the demands of both the market and the smallholders. This is a combination of the poor governance structures and persisting limited asset base of the smallholder farmers and their association.

5.3 Partnership between smallholders, association, and a commercial dairy

Establishing a new partnership with the commercial dairy, Shambani Ltd., could mitigate some of the association's shortcomings and open up for larger and more consistent demand for goat milk, which would allow all members to supply milk every day. It could also open up for additional members. This partnership will, however, place smallholder dairy farmers in a weaker position relative to their partners when going from a relational governance typology to a new and more captive form of value chain governance. This is caused by asymmetric relationships of power and information, not to mention the higher transaction costs associated with partnering. Additionally, the farmers need to weigh the positive aspects of being able to supply larger amounts of milk against the loss of being in control of the value-adding of milk.

In a partnership with a commercial dairy, the smallholder goat milk producers and the association will continue with their main activities of supplying and collecting milk (as seen in R1 in Figures 6 and 8), but will no longer process milk into drinking yoghurt. Rather, the new partner will collect the bulked milk and process it before distribution for sale, which is illustrated by the reinforcing feedback loop R2 in Figure 8. The university, or other enabling partners, will continue to provide strategic support to the three actors to reduce the risks of entering into a new partnership. These main activities can seem straightforward, but a successful partnership might mean different things for different partners as they measure success differently. For smallholders, success can be defined individually as profitable milk production, and collectively as participation by all goat milk producers who would like to participate in the value chain. For the association, success could be defined as profitable operations while assuring good services and conditions for their members, and meeting demand for milk. For the dairy, the goal is profitable operations. The shared value chain goal could be profitable value-adding of high quality goat milk products for all actors involved. It could further be specified by agreeing to who gets what share of the value addition.

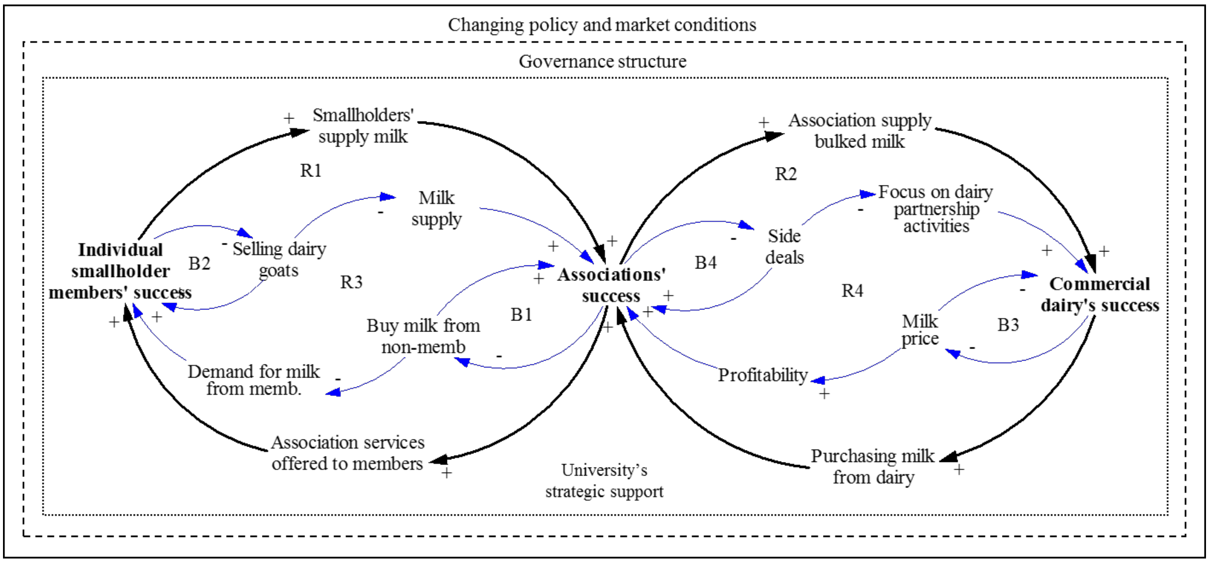

Figure 8: Extended accidental adversaries model, focusing on partnership between smallholders, association, and dairy. Source: Developed by the authors

Good management is still crucial for the association to be able to collect enough quality and quantity of milk to meet the dairy demand each week. Despite opening up for all members to supply, they might end up in a similar situation to the previous one, in not having enough milk if they fail to attract suppliers and possibly new members to meet the quality conditions and increase in demand. The same balancing loops (B1 and B2) are still present in the extended AA model in Figure 8. If this situation persists over time, and the previously discussed leverage points are not taken into account or successfully implemented, the dairy could take control over the collection themselves. Interviews with the dairy revealed that this is a likely scenario since the dairy does not trust the association members to collect quality milk. One reason for this is the challenge members face in rejecting milk from friends and family if the milk is not up to the required standard. The association could then focus on its other activities. However, withdrawing from the negotiations regarding conditions such as price, quality, quantity and services would most likely represent a loss to the farmers.

The dairy, along with all the partners, must consider both the partnership objectives and their own local objectives of running a profitable business. Being the lead firm in the value chain, the dairy has the power to control conditions such as price, in addition to the quality and quantity of milk. The dairy has to compete in larger markets with several other dairies and their multiple products. Cow milk products in towns are priced considerably lower than the goat milk sold in Mgeta. The dairy's strategy should be to achieve a price premium on goat milk products in accordance with its favorable health characteristics (Zervas & Tsiplakou 2013). Despite this, the dairy might still be forced to offer the smallholders a lower price for their milk than before, in order to run a profitable business, as illustrated in B3 in Figure 8. The milk price in the market might also change when entering the market, when the product is positioned in the market, or owing to other swings in the market.

Smallholders, through their association, need to consider what an acceptable minimum price will be to produce goat milk profitably, also taking into account the possibility of increasing production due to higher demand. If the price is too low, the association might focus on other activities such as the input supply shop, offering veterinary services, and even selling dairy goats to regional markets (B4), and focus less on the partnership activities of collecting quality milk. The balancing feedback loops (B3 and B4) would result in an AA-type of scenario (R4), and limit the success for the different partners.

The governance model in Figure 9 further highlights important governance aspects in the potential new partnership. Adding value to goat milk in Tanzania will result in the development of a new product in the market. The success of the dairy will therefore depend on the dairy's ability to position such products successfully, given the nature of competition in the market. The power of other competitors in the market relative to the dairy decides how much the market influences the dairy and its autonomy, and determines whether the dairy will be able to achieve its partnership objectives versus local objectives, and ultimately decide their health and success (see the reinforcing R9 and R10 loops, and balancing B7 feedback loops in Figure 9). This again influences the dairy's strength relative to the association (B6), which typically will be strong, given that the dairy is the chain leader. The association's autonomy will be low, influencing its activities and ability to achieve both partnership goals and local objectives, which impacts on the association's health/success (R7). A similar situation exists in the relationship between the association and the smallholders.

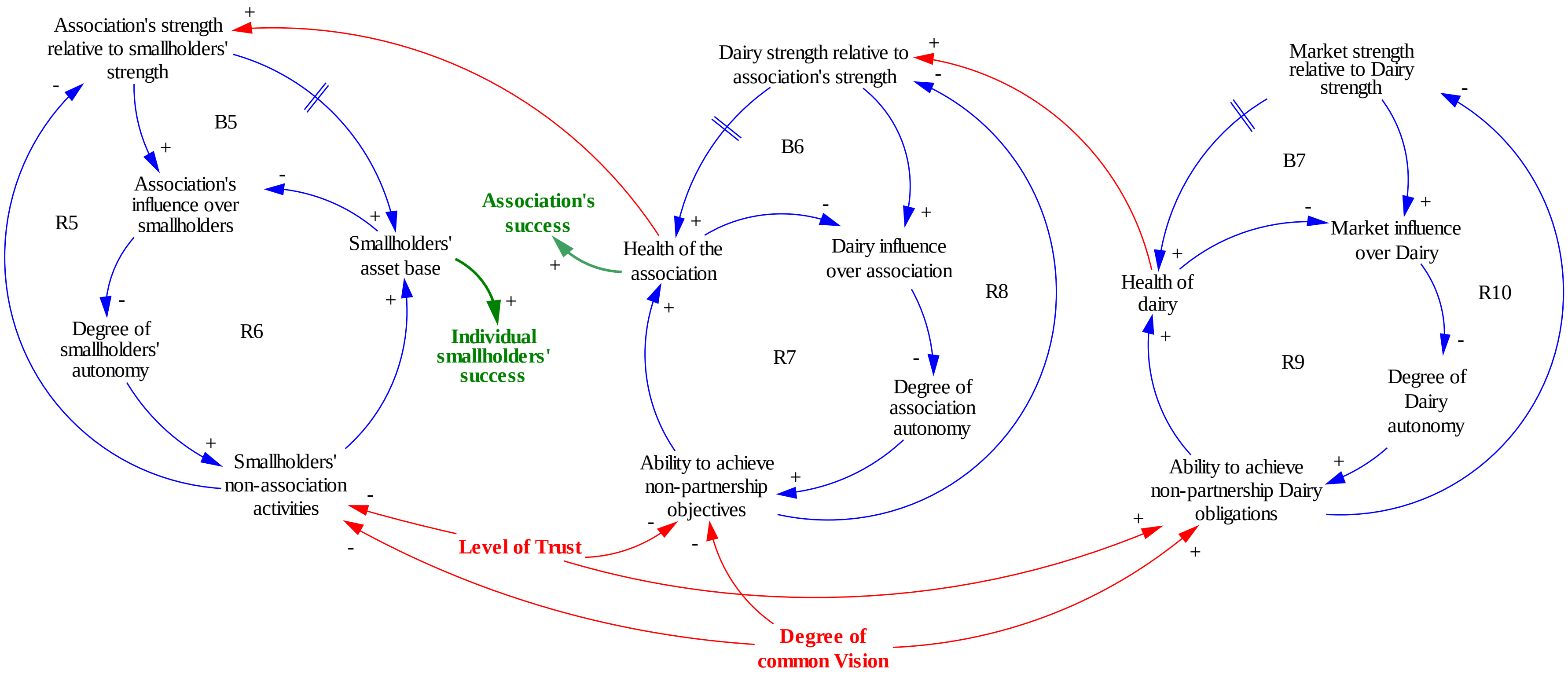

Figure 9: Governance model of partnership between smallholders, association and dairy. Source: Developed by the authors

Ensuring ownership of a common vision with an agreed-upon time frame is important, in order to understand the different phases the partnership will go through in terms of costs and benefits; this is a leverage point applied in Figure 9. To achieve this vision, a strong association relative to the dairy is important to negotiate conditions such as minimum price for milk, volume, quality requirements, collection routines, and training. The enabling environment can also support negotiations, ensuring rights of the farmers, and offer other services such as training.

Building trust is another crucial leverage point, which can be achieved through good flow of information, transparency in plans and strategies, and following up on these regularly. If this is not ensured from the beginning, the inherent power asymmetry between the dairy and the association will increase, and hence the strength and influence of the dairy over the association will remain high and further affect smallholders negatively. If this is the case, both the association and individual producers might focus more on other local objectives than on fulfilling the partnership objectives. It is important to accept the high transaction costs that arise in the beginning of a partnership, so as to achieve good value chain governance. When entering into a partnership, it is valuable to consider both short- and long-term consequences, since a possible danger is sacrificing long-term value creation for short-term performance (Brinkerhoff 2002).

Several other leverage points and scenarios could be discussed using the two systems models to analyze partnerships and governance structures in value chains. These models consider both the short and the long term, as well as the intended and unintended consequences of decisions made. Such discussions could support the partners and their enablers, in achieving a good foundation for establishing and implementing a successful value chain partnership.

6. Conclusion

The smallholder goat milk value chain in Mgeta, Tanzania, is a good example of the difficulties that smallholders experience in accessing markets, and in being a part of coordinating value chain activities. With support of strategic partners, they have experienced some degree of value chain upgrading, although with a limited degree of success. This paper illustrates how a systems approach for analyzing partnerships and changing governance in value chains can be used to assess the potential for existing and new partnerships in agricultural value chains such as the Mgeta milk value chain.

The framework provides valuable additions to the theory of value chain governance and partnerships. It offers insights into the intentional and unintentional consequences of decisions made in a complex and dynamic value chain system with multiple actors working towards their own objectives, and towards a common overall goal. It can identify weaknesses in the governance structure by analyzing the consequences of decisions made, and how issues such as trust and a common vision play vital roles for the outcomes of decisions. It can also support the identification of interventions to improve the mechanisms needed for developing sustainable solutions. It is crucial that good and strong governance structures are identified. These structures need to be maintained at high levels to ensure that partnerships survive individual short-term fluctuations as well as long-term market trends. By addressing the means by which partnerships affect value chain governance, and understanding the effect of governance on smallholder farmers, donors and policy-makers can be helped to more successfully intervene in pro-poor value chains to ensure inclusion of smallholder farmers.

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ARTICLE 2

Participatory system dynamics modelling for dairy value chain development in Nicaragua

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Abstract

The use of system dynamics (SD) tools can add valuable insights when identifying and evaluating priorities for pro-poor value chain upgrading. However, to better understand the complex systems in agricultural value chains and to develop useful models, a participatory modelling process is important. This paper highlights the group model building (GMB) process of the dairy value chain in Matiguás, Nicaragua, one of a few examples of participatory model building in developing countries. The results confirm several benefits with participatory SD modelling including team learning, a greater understanding of the value of modelling, and a tool for decision-making and priority setting.

Introduction

Smallholder farmers are an important component of international food and nutrition security, but face numerous challenges when trying to improve their livelihoods. While there is limited participation of smallholder farmers in increasingly professionalized and complex agricultural value chains, opportunities exist for smallholders to access markets, which can contribute to a range of positive, pro-poor impacts. One of the virtues of focusing on the value chain, instead of a specific sector or commodity, is the ability to characterize more broadly the system in which smallholder farmers can take part, and to identify the role that contextual factors such as governance play in determining market access (Rich et al. 2011).

A number of value chain frameworks have been developed by NGOs and donor consortiums (e.g. Making Markets Work Better for the Poor, World Vision, SNV) to guide practitioners on the analysis and development of pro-poor value chains. These toolkits have been mainstreamed to engage stakeholders to work in a systems setting as a means of developing common goals, and the promotion and development of new, pro-poor market opportunities. However, an important challenge and limitation of value chain analysis (VCA) and value chain toolkits is that they are highly qualitative and descriptive in their orientation. In particular, it is difficult to project *ex-ante* what impact or outcome different interventions might have within these complex systems (Rich et al. 2011). As the introduction of new interventions will cause changes in both marketing and contextual features of the value chain, various feedback mechanisms may be activated that could undermine or reduce, as well as improve, the effectiveness of a specific intervention over time. As such, it is important to identify analytical frameworks that can provide a richer understanding of the impacts that policies could have on the value chain and its participants. Equally important in development settings is to find the means to operationalize the process of impact assessment in environments where data is poor or unavailable, and to ensure a process of stakeholder engagement throughout.

System dynamics methods are one means to address these gaps in value chain analysis. A system dynamics (or SD) model maps the flows, processes, decision rules, and relationships between actors that operate within a complex system (Sterman 2000). It is highly interdisciplinary and can be used as a tool to test and analyze interventions and policies. Recent research on value chains has revealed the utility of this approach in agricultural and livestock systems in *ex-ante* testing of the dynamic impacts of feedbacks from different policy and technical interventions within the chain (Rich et al. 2011, Naziri, Rich, and Bennett 2015).

A particular advantage of SD models is that they can be conceived and developed through participatory processes with stakeholders in the field. In particular, many analysts use what is known as group model building, or GMB, to develop their models jointly through participation and direct collaboration (Vennix 1996). Several methods for developing models with stakeholders exist (e.g. see Voinov and Bousquet 2010 for an overview of different methods). However, in the context of developing SD models, GMB is particularly appropriate, as the participatory process is specifically oriented towards the explicit use of the language and concepts of system dynamics in the development of models with stakeholders. In addition, GMB is especially relevant when there are diverse types of stakeholders involved, when many different intervention options exist, and when it is difficult for stakeholders to understand individually the possible consequences of a collective decision made within a complex system (Vennix 1996, Andersen, Richardson, and Vennix 1997).

Despite the potential applicability of GMB in a developing country and in a value chain context, little research has utilized this approach (an exception is McRoberts et al. 2013). The purpose of this paper is, therefore, to demonstrate and assess how a GMB process can be applied in building models that contribute to inclusive decision-making and pro-poor value chain development. We provide a detailed example of the participatory SD model building process applied in the analysis of the dairy value chain in Matiguás, Nicaragua. The dairy sector is large and important in Nicaragua, and Matiguás is one of the areas where most of the country's milk is produced. The area is smallholder-focused, with several cooperatives and private milk collectors that supply the dairy industry in the capital Managua. Given the shifts towards more commercial and export-oriented markets, it is a priority of the government to understand the scope and impacts of policy options available to promote the continued inclusion of small- and medium-scale producers (MAGFOR 2013, Polvorosa 2013). The research objectives of the project include (i) an identification and understanding of the dynamic processes in the dairy value chain in Matiguás, Nicaragua and (ii) a collective discussion of relevant interventions, policies, and decision-making processes based on these processes, and their possible implications on smallholder competitiveness.

In this paper, we first provide some background to system dynamics with particular focus on group model building. We follow this with an introduction to the study area of Matiguás, Nicaragua. We then give a detailed account of the research methodology, offering insights into the implementation of a participatory value chain modelling process. We conclude with perspectives, lessons learned, and challenges of using this approach in developing pro-poor value chains.

Participatory system dynamics modelling

Value chains and system dynamics

A value chain denotes the various processes and actors involved in the development, transformation, marketing, and final retail of a good or service (Kaplinsky and Morris 2001). In conventional value chain analysis and development, practitioners analyze the structure of the system through a process of participatory actor mapping with stakeholders. This provides insights on flows of goods and services, how different actors interact with one another and identifies the contextual factors (termed governance). Governance examines how different decisions are made and implemented, how activities are coordinated, and how decision-makers are held accountable. The lead stakeholder(s) in the value chain often have the power to control the terms of participation and influence the involvement of other actors (Gereffi, Humphrey, and Sturgeon 2005). This analysis is used to inform the development of upgrading strategies to add value for the actors. Upgrading strategies can involve the development of new products, improving processes, changing ones position in the chain, or moving into a new chain all together (Kaplinsky and Morris 2001, Bair 2009). It is particularly important to pay special attention to vulnerable groups such as smallholder farmers when upgrading value chains in developing countries, so that the interventions do not have the opposite effect of the desired development outcome (Bolwig et al. 2010) .

As noted, the process of value chain analysis is largely qualitative and descriptive, making it difficult to evaluate the benefits and costs associated with different intervention options. Rich et al. (2011) proposed the use of SD tools as a means of complementing value chain analysis. System dynamics is a computer-aided, interdisciplinary approach to policy analysis and design (Sterman 2000). What SD models provide to value chain analysis is a quantitative overlay to conduct scenario analysis. A standard value chain mapping exercise produces only static snapshots of the system processes. System dynamics software enables studying the behavior of these processes over time.

SD models are built on the concepts of stocks, flows, and feedback loops. Stocks denote the accumulation of any good or service at a particular period of time. In a livestock system, the number of animals on a farm or the volume of milk processed are considered as stock variables. Flows define the rate of change into and out of a stock and represent the decisions that are made to change stock values. Sales of cattle by a farm (units: head of cattle sold per week) would be an example of an outflow, while purchases of raw milk (units: liters of milk purchased per week) by a milk processor would be an example of an inflow. Different technical parameters regulate the speed by which inflows or outflows change the level of a stock. Within a system, feedback loops exist when decisions change one component of a model and initiate changes in the conditions and information of another component that influence the broader system (Sterman 2000). Figure 1 provides an illustration of how stocks, flows, and feedbacks are represented in SD modeling.

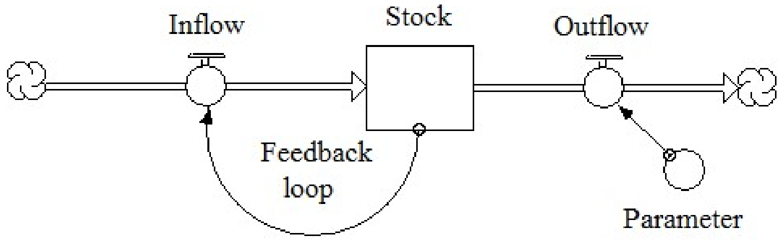

Figure 1: Illustration of stock, flows and feedback. Source: Modified from Sterman (2000)

Group model building

Group model building, or GMB, is a participatory method that includes various relevant stakeholders in constructing a SD model. GMB combines bottom-up and top-down perspectives on systems problems, especially those found in value chains, thus increasing the credibility of proposed solutions. The GMB process offers an opportunity to take part in, understand, and influence decision-making in the value chain for all stakeholders (Vennix 1996). It can also uncover different attitudes and understandings among the value chain stakeholders during the process, a valuable outcome of participatory research (Gaventa and Cornwall 2008). GMB is also a good tool of building consensus and commitment to the final chosen strategy since all stakeholders are involved in constructing the model, testing suggested interventions and policies, and making choices. By their nature, GMB sessions are interactive and iterative. Furthermore, it can help to achieve stakeholder buy-in and commitment to selected policies and value chain interventions and assure sustainability after project end (Hovmand 2014, Andersen, Richardson, and Vennix 1997, Cornwall and Jewkes 1995). It is also particularly useful in environments where data is scarce.

Critiques of participatory research remark that true participation is often not achieved, limited by either temporal constraints associated with the research process or an inability to achieve sufficient heterogeneity in participants. Others criticize that unintended negative consequences of the process often is not considered. Participatory research further puts pressure on ensuring equal participation of farmers and other stakeholders, which necessitate focus on issues such as power, knowledge, interests, and freedom of speech. Equal ownership to results is also important (Cornwall and Jewkes 1995).

A GMB process starts with problem identification and definition, whereby the system is conceptualized through identifying different elements in the system and their relationships. The outputs of a GMB session can either be a qualitative model of the system that can help in joint learning about the system itself or the development of quantitative models that can be used to run scenarios of different interventions. This is subsequently used to formulate dynamic hypotheses about the causes of various problems. The quantitative modelling involves parameterizing proposed relationships, followed by validation, testing and analysis to develop policy recommendations. The final step is to assess the process and the process outcomes (Vennix 1996, Sterman 2000).

Within the value chain, a GMB process ideally includes key stakeholders, such as producers, processors, traders, and retailers. Most importantly, GMB sessions need to include those who have local knowledge and are affected by and can implement changes (Gaventa and Cornwall 2008). It should also include those that work with the value chain, often called the enabling environment, since they have more power and resources to initiate and support interventions. These are stakeholders that offer services and support to the key stakeholders in the value chain, such as credit- and research institutions, NGOs, and government agencies. Ensuring inclusion of women is important to highlight the direct and indirect roles women play in value chains (Rubin and Manfre 2014).

The selection of participants in a GMB project is therefore important. It can be a small group of around five to seven people or a large group of more than ten or twelve (Vennix 1996). In value chains with many stakeholders, a larger group might be necessary. Including one too many is often better than one too few since those excluded from the process may easily resist the resulting conclusion from the GMB process (Vennix 1996, Voinov and Bousquet 2010). Creating an environment for active participation by all is critical (Gaventa and Cornwall 2008).

Other considerations with a GMB session include establishing the roles and responsibilities of the facilitation team, and procedures used to facilitate discussion. A facilitation team typically consists of the lead facilitator, a recorder that takes detail notes in each session, a modeler, a process coach paying specific attention to the group process- and dynamics, and a gatekeeper that is the liaison between the facilitation team and the participants. One person could take on several roles, but a minimum of two people is advised, and more if working with a large group (Vennix 1996). Likewise, the GMB process can start from scratch with the GMB participants, or can start with a preliminary model. This depends on the number of participants and facilitators, the time available, the location, cultural setting, and financial resources (Vennix 1996). Scripts are often used to guide each session where the process, procedures, and the time set aside for each step is agreed upon to ensure progress in the modelling process (Luna-Reyes et al. 2006, Andersen and Richardson 1997).

Despite the many highlighted benefits, McRoberts et al. (2013) provide one of very few examples of participatory model building of a value chain. They constructed a SD model focusing on small-scale dairy development in Mexico and tested the possibilities of collective action to produce goat cheese by focusing on key biological and economic factors. They concluded that a systems-based participatory approach can help test potential development and agribusiness interventions.

Study area

Nicaragua is an agricultural country with livestock being the most important component, contributing to 13% of the national GDP, and 45% of the national value of agricultural production in 2013 (MAGFOR 2013). The size of the dairy sector has increased over the last decade and is one of the government’s priority areas. National milk production has increased over the past five years and is estimated to be two million liters per day, where only 25% is absorbed by formal processing plants and 75% by the informal sector (MAGFOR 2013, Holman 2014).

The research analyzed the Nicaraguan dairy sector at the meso level and selected the dairy value chain within the Matiguás municipality in the Matagalpa region, 160 km away from the capital Managua. Matiguás municipality has a population of nearly 50,000, where over 80% are livestock keeping households. Matiguás is part of the “Via láctea”, the “Milky Way”, which consists of four municipalities that produce 20-30% of Nicaragua’s milk (INIDE-MAGFOR 2013). Dual-purpose cattle is the most common, with a high number of small- and medium-scale producers (80%), which is the target group of this research. In Nicaragua, small-scale producers typically farm less than 14 ha of land, own between 2 and 20 cows, and produce on average 20 liters of milk per day. Medium-scale producers farm 14 to 100 ha and produce around 50 liters/day. In total, about 100,000 liters are produced per day in Matiguás. Most of the milk (60-65%) is collected through one of the five cooperatives and supplied to the large milk processors in Managua, as illustrated in Figure 2. About 35% of the milk is collected by private collectors and supplied to the industry or to semi-industrial processors who primarily export to El Salvador. There are also numerous small local processors in Matiguás, which are part of the large informal dairy sector in Nicaragua (Polvorosa 2013, Alcaldía Municipal de Matiguás 2011). These three sub-chains make up the dairy sector in Matiguás. This paper focuses on the cooperative driven chain that reaches national and international markets through contracts with commercial dairies. Studies show that the small- and medium-scale milk producers who are part of the cooperative chain receive higher and more stable prices throughout the year, compared with other producers who sell to alternative chains (Polvorosa 2013).

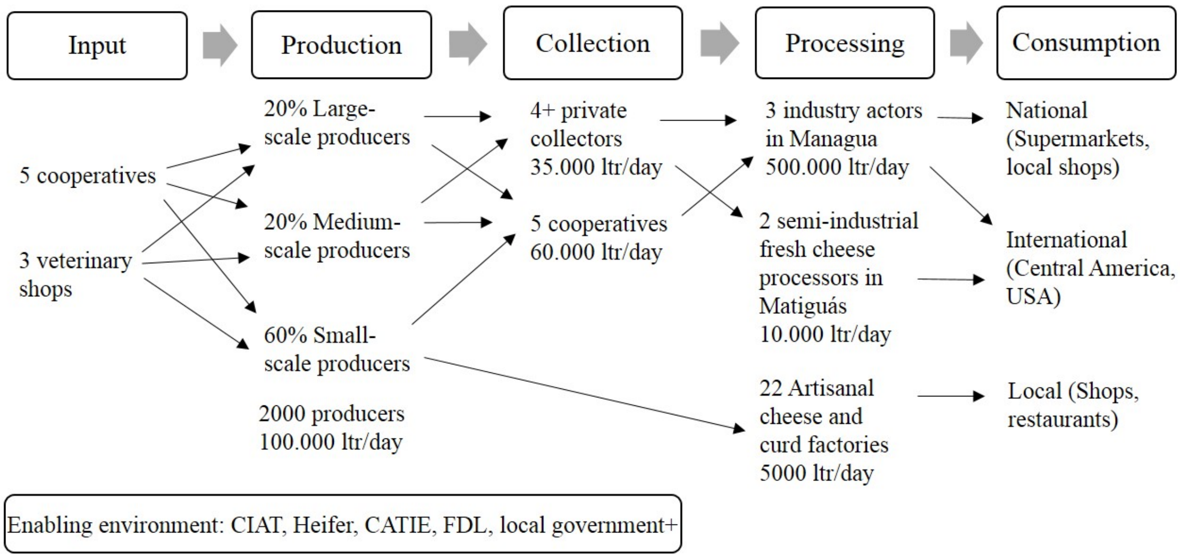

Figure 2: The Matiguás dairy value chain. Source: Modified and updated from Modified and updated from Polvorosa 2013, Flores et al. 2011, Velásquez and Manzanarez 2014.

About seventy percent of small- and medium-scale milk producers are organized in one of the five dairy cooperatives in Matiguás (Polvorosa 2013). The cooperatives provide them with access to the formal market through the collection centers and other support services such as credit, input, and veterinary services. One of the five cooperatives is the largest dairy cooperative in Nicaragua with over 900 members. Despite the influence of cooperatives, the three industrial processors lead the chain, tightly coordinating transactions through strict food safety regulations, milk prices, and demand for milk. Consolidation in the industry has reduced the number of main players from five to three large-scale dairy processors over the last few years. As a result, the negotiation power of the cooperatives is reduced.

Milk demand is regulated through a quota system based on quantities of milk supplied across seasons. Producers are encouraged to increase production during the dry season with low production to stabilize milk supply. Milk prices are also higher during this season and offer an opportunity to increase their income. Milk is additionally classified within an A, B, C quality-system with different prices. The collection centers put the industry regulations into practice by controlling milk quality and quantity, and receive no support from the lead firms, which control the conditions (Polvorosa 2013).

Farmers need to produce an average of 40 liters of milk per day to cover their costs of production and supply, as well as to become a member of a cooperative. Investments in more intensive and productive dairy farming practices are necessary to achieve this for some small-scale producers. Proximity to a collection route and basic infrastructure such as roads, water, and electricity are also important to access the high value dairy value chain. The smaller and less resourceful farmers face the highest restrictions to supply to collection centers, and can result in exclusion from the higher value dairy value chain. The alternative is to supply the semi-industrial collectors with fewer quality and quantity requirements, but with highly fluctuating prices, or the traditional cheese makers with limited requirements and low prices (Polvorosa 2013).

The enabling environment consists of various organizations and research institutions who provide support to cooperatives and producers to remain competitive in the increasingly commercial dairy industry in Nicaragua. Several credit institutions such as FDL, a leading microfinance institution, provides credit to farmers to meet the higher requirements when participating in the formal dairy chain. The different analyses of the dairy sector in Matiguás and the “Via láctea” by enabling environment such as the International Center for Tropical Agriculture (CIAT), Heifer International, the research and development institute Nitlapan, and the Tropical Agricultural Research and Higher Education Center (CATIE) highlight the potential of increasing the amount of milk produced, improving milk quality, and enhancing coordination among the involved actors (Polvorosa 2013, Flores et al. 2011, Velásquez and Manzanarez 2014).

The current increase in milk production is primarily due to an increase in the number of animals and the use of more land for livestock purposes. However, land availability is close to reaching its limits, thus requiring strategies for achieving milk production increases and stability. Stabilizing the volume of milk throughout the entire year and improving animal productivity are two of the biggest challenges, especially since there is little room and expensive to continue land expansion for livestock purposes. In addition, milk collection centers face underutilization of their capacities, especially during the dry season from January to mid-May (Alcaldía Municipal de Matiguás 2011). Despite several studies and plans, none have presented any justified projections of potential impacts if any or all of the identified interventions were to be implemented. This suggests a need for methodologies that can better evaluate returns to alternative intervention strategies with a specific focus on the inclusion of small- and medium-scale dairy farmers.

Methodology

Four GMB sessions were held between March and June 2015, with a follow-up exercise conducted in mid-April 2016. Key informant interviews with stakeholders were also held during this time. The sessions included project facilitators, a reference group, and the group model building participants. The facilitation team consisted of one project leader and lead modeler, one expert modeler, three group facilitators, one recorder, and one gatekeeper, which participated at different times. The reference group comprised of researchers from CIAT based in Managua, Nicaragua and Cali, Colombia that contributed with technical and local knowledge to the model and modelling process. Table 1 highlights the research design and timeline, including the number of participants and the goals of each stage of the GMB process.

The GMB participants represented each node of the value chain and those working in the enabling environment, including small- and medium-scale farmers (4 participants), cooperatives (3), local processor (1), local government (3), and institutions (7) working on value chain interventions, such as Heifer International, CIAT, CATIE and Nitlapan. The target number of representatives from various stakeholder groups was set to fifteen, a relatively large group for GMB sessions, to include all actors in the dairy value chain. The specific participants were selected in cooperation with the gatekeeper who was a local project coordinator working in the Matiguás dairy value chain. Only 14% of the GMB participants were women, reflecting the male dominance of the livestock sector in Nicaragua (Flores et al. 2011). The male dominance complicates the selection of women, especially from institutions working with the dairy value chain in Matiguás. Our selection of participants focused on including representatives from all nodes of the value chain, including the enabling environment, and despite trying did not achieve the ideal gender balance. The number of participants in each GMB session varied, as well as the participants themselves, due to busy schedules and varying interest – a common challenge in participatory research (Cornwall and Jewkes 1995). On average, thirteen participants attended each time and each group of stakeholders was represented in every session.

Table 1: Project timeline with an overview of specific GMB activities, participants, and goals

Date	Activity	Participants	Goal
25 - 27.03.15	Scoping trip	1 Researcher 1 Research assistant 2 field facilitators 1 Gatekeeper	1. Familiarize with the study area and the various actors 2. Interview different actors in the dairy value chain in Matiguás
08.04.15	Project presentation for municipal government and key institutions	2 Presenters 1 Research assistant 1 Gatekeeper 8 participants	1. Achieve final acceptance and go ahead from gatekeeper and municipal government 2. Participant selection
13.04.15	Reference group discussion 1	2 Presenters 1 Recorder 6 participants	1. Achieve basic knowledge of SD and GMB in reference group 2. Practice run for GMB1
15.04.15	GMB 1	4 Facilitators/ Recorder 14 participants	1. Introduce the research to the GMB participants 2. Agree on the value chain goal 3. Identify and prioritize problems, and discuss their causes and consequences 4. Make reference mode(s)
28.04.15	GMB 2	3 Facilitators/ Recorder 12 participants	1. Introduce the concept and language of system dynamics modeling 2. Start building the model
06.05.15	Reference group discussion 2	2 Facilitators/ Recorder 3 participants	1. Discuss draft model and way forward
19.05.15	GMB 3	4 Facilitators/ Recorder 14 participants	1. Validate and add to the model 2. Add numbers to the model
16.05.15	Reference group discussion 3	2 Facilitators/ Recorder 6 participants	1. Discuss draft model and way forward
16.06.15	GMB 4	3 Facilitators/ Recorder 9 participants	1. Add more numbers to the model 2. Assess the GMB process so far
18.04.16	Reference group discussion 4	2 Facilitators/ Recorder 3 Participants	1. Validate SD model 2. Present and discuss preliminary findings 3. Prepare last GMB
20.04.16	GMB 5	4 Facilitators/ Recorder 14 participants	1. Validate SD model 2. Present and discuss preliminary findings 3. How to access and use the model 4. Assess the GMB process and value of SD model
23- 24.04.16	Reference group discussion 5	1 facilitator 2 participants	1. Discuss and verify edited and added structures and data

Source: Developed by the authors

Four GMB sessions were planned from the beginning to interact with participants over time, as well as to give them time to absorb the information and new ways of thinking. They were held approximately every other week and had a duration of around three hours each. An overall plan was made for the different sessions, with detailed scripts developed before each session focusing on goals, activities, and timing, although with flexibility for *ad hoc* changes. After each session, detailed summaries focusing on the process, the data collected and the decisions made were written to ensure recoverability. Each session was also evaluated among the facilitators and changes were made accordingly in the next session, following an iterative research design. A follow-up trip to Nicaragua in April 2016 focused on presenting, validating, and discussing the model and preliminary results with the GMB participants and reference group. An assessment of the entire process was also conducted with the participants of the last session, GMB5, through plenary discussion and a short individual questionnaire. Twelve of the fourteen participants in the last GMB session answered the questionnaire.

In addition to the GMB sessions, semi-structured individual interviews were conducted with the leadership of the cooperative, a private dairy industry actor in Managua, The Nicaraguan Chamber of the Dairy Sector (Canislac), and different local credit institutions before and during the GMB process. These interviews provided background and in-depth knowledge about the various actors and processes and discussed specific aspects to be covered in the SD model.

Participatory model building of the Matiguás dairy value chain

Group model building (GMB) process

The roadmap of the GMB process is illustrated in Figure 3, and highlights the progress made during each step of the process. The scoping trip and the initial meeting with the local government and key institutions provided the necessary background information and introduction to the field site to start implementing the model building process with the reference group and selected GMB participants.

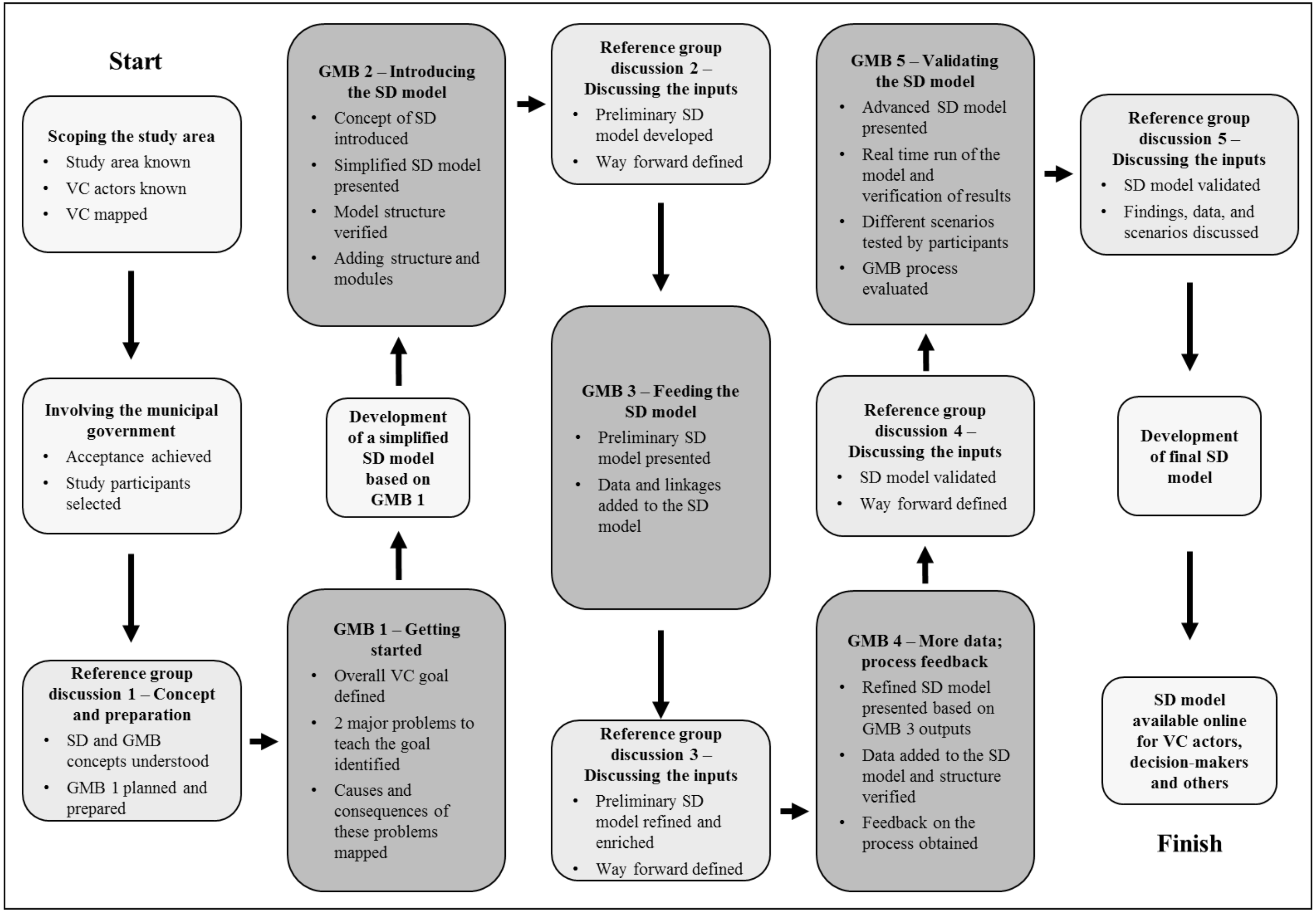

Figure 3: Overview of the progress in the GMB process. Source: Developed by the authors

The first GMB session established goals and problem variables. Plenary discussions with participants defined the goal for the Matiguás dairy value chain as: "Contribute to the national goal of increasing milk production in terms of quality and quantity, and achieve a higher income for the actors that are involved in the chain". Agreement on a common value chain goal set the stage for focusing on the entire chain and its dynamics, and not on individual nodes. Next, fifteen problems associated with reaching the goal were identified in an individual card-writing exercise followed by a round robin sharing and discussion session. Each participant voted on the top three problems. The highest ranked problem was deficient animal feeding systems, followed by a lack of incentives to improve milk quality. The group discussed and agreed to proceed with these two problems, which encompassed several of the other problems identified. Causes and consequences for the two main problems were identified and discussed in small groups. This was followed by discussion and mapping of these causes and consequences. An example is that poor pasture and forage management and limited feed availability during the dry months are causes of deficient feed availability, leading to low cow productivity, low milk production, and low profitability among producers. The SD model therefore focused on these identified issues. The discussions and exercises gave participants an understanding into the complex nature of the Matiguás dairy value chain. The group also defined reference modes that illustrate the historical and future behavior of milk production, with and without possible interventions. Figure 4 denotes the outcomes associated with GMB1.

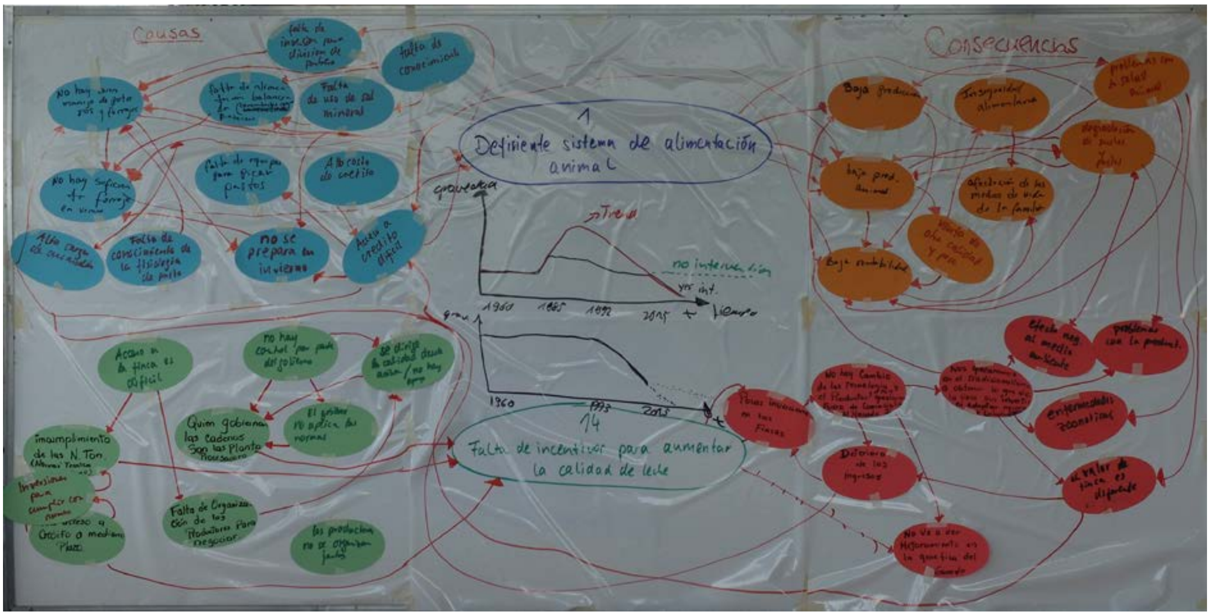

Figure 4: Outcomes generated from GMB1 Photo: CIAT staff

In the second GMB session, the concepts and language of system dynamics was introduced. A simple cow production model was introduced and explained step by step using the storytelling function in the software modelling program, iThink[1]. Storytelling provides a platform for annotating and animating specific parts of a model to ease in model explanation. Next, we ran a few model simulations to illustrate how changes and results can be presented in an SD model.

This introduction facilitated the presentation of a simple SD model structure focusing on cow and milk production that was used as a starting point for the Matiguás SD model. We had planned to verify and add to the structure in plenary, but due to unequal participation in the beginning, we split into small groups. Three groups were formed based on the focus from the previous GMB session: cow production, milk quality, and feeds. At the end of the day, the groups presented and discussed their group work in plenary, as seen in Figure 5 and Figure 6. These presentations revealed that each group's work overlapped due to the interrelated issues in the value chain. GMB2 resulted in adding feeds as a separate module to the model alongside its feedbacks with milk and cow production.

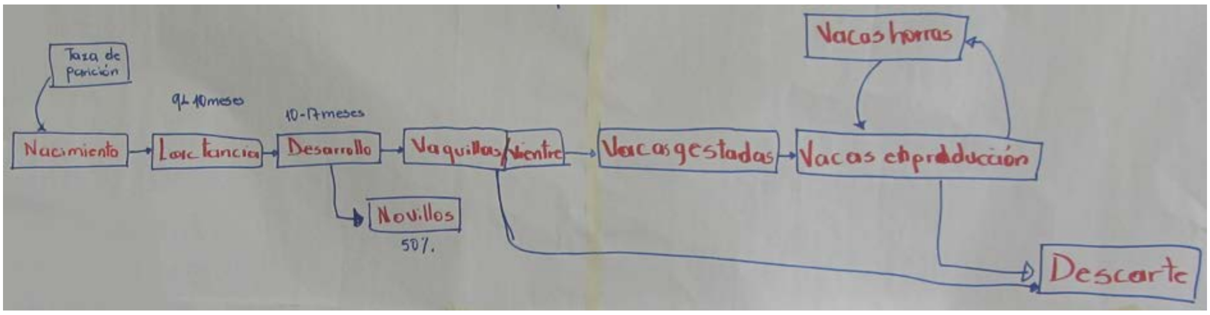

Figure 5: Herd module from group work illustrating the development of dairy cows from birth. Photo: Helene Lie

[1] Available here: http://www.iseesystems.com/softwares/STELLA-iThink.aspx

Figure 6: Presentation of the group work in plenary for discussion and consensus. Photo: Helene Lie

Based on GMB2, the model structure was further developed by the lead modeler and the reference group. For example, the identified modules from the group work were re-formulated to follow the SD language of stocks, flows, and auxiliary variables. Additionally, a financial module was added to gather the financial data and highlights feedbacks with the other three modules. At this stage, the model remained qualitative.

GMB3 and GMB4 focused primarily on model parameterization and data collection to enable the simulation of scenarios. The structures and the relationships between the modules were also further developed. In GMB3, the current version of the model was printed on large sheets of paper to be used in group work. The group members were assigned beforehand to ensure that each group contained producers and that those with specific knowledge were put in the most relevant group. Each group added data on post-it notes and changed and added structures and linkages between the modules, as seen in Figure 7.

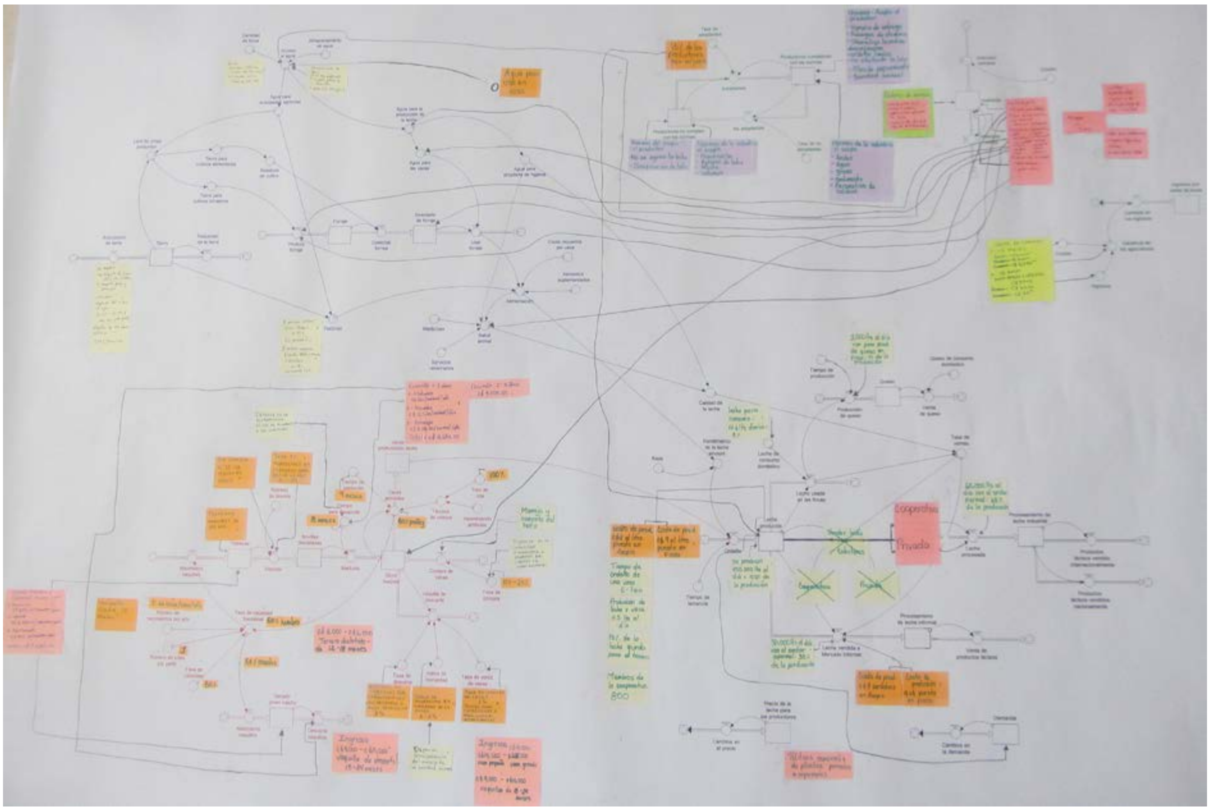

Figure 7: Printed model used in GMB3 showing the four modules with added linkages, structure, and data from group work discussions. Photo: Helene Lie

Data collected in the milk module included: (a) the total amount of milk produced by small- and medium-scale producers, (b) the quantity of milk sold to different channels such as home consumption, formal- and informal sectors, and (c) milk prices. The herd module required information on technical parameters e.g., the amount of time needed for calves to mature, the quantity of milk produced each day by a dairy cow, and the costs of cow production. The feed module focused on data associated with feed use, land use by pasture type, and feed production costs. All data focused only on small- and medium-scale producers. The data used was based on consensus among group members. The diversity and experience of session participants allowed us to efficiently collect the necessary primary data. Additional data on the number of cows and the total amount of land in Matiguás were taken from the national census as a starting point (INIDE-MAGFOR 2013). GMB4 followed GMB3 by verifying the current structure and gathering additional data in groups. Feedback on the process was also conducted in GMB4, which was initially planned to be the last session.

After GMB4, the team conducted several interviews with key stakeholders of the value chain. The lead modeler and facilitator continued to work on the model based on the large amount of data from the last two GMB sessions, and continued discussions with key members from the reference group on major model decisions. The modeling focus narrowed to assess the top identified problem, deficient feeding systems.

The last GMB session, GMB5, was organized in April 2016 with reference group meetings before and after the group session. GMB5 served to present, discuss, and validate the model and preliminary results which data and time limitations prevented during GMB4. The updated model was presented using the storytelling function in iThink. The model and baseline results were run and discussed in real time based on the baseline data collected in the previous GMB sessions. We then ran scenarios where we changed land allocation and cow productivity. There was active discussion of the structure and results in plenary, which was followed up in two groups focusing on the different modules: herd, milk, feeds, and finance. These discussions centered on feeding systems, specifically on the use of improved pastures and concentrates, and water availability. The individual groups, different facilitators, and some participants also tested different model scenarios during the session. GMB5 added valuable information to complete the model and ensure its usefulness. The reference group continued the discussion from GMB5. They focused specifically on data and scenarios in the feeds section, which is their expertise and a topic that can be difficult for the GMB participants to provide details.

GMB process reflections

Considerable effort was put into planning and implementing each GMB session. Specific emphasis was placed on ensuring equal participation of all participants despite differences in their position in the value chain, power structures, and available knowledge. For example, two participants who could not read or write very well were given support when participants were instructed to write something down. Printed models were also always presented orally so that all could follow the more detailed discussion. Producers ended up sitting together in the back in the beginning of GMB1 and did not contribute much in the first plenary discussions. Due to the iterative research design, the GMB implementation plans changed during the process to focus more on smaller group work than plenary discussions, and this resulted in higher producer participation.

There were also strong personalities with expertise knowledge and high confidence. This put pressure on the facilitators with respect to enabling all to participate. They sometimes had to facilitate more firmly who could talk when and for how long. Only one participant, a producer, reported that he did not feel free to express his mind. However, all participants reported that they would participate in a process like this again if they were given an opportunity.

In terms of data collection, the GMB process provided invaluable information that would otherwise have been difficult or time-consuming to obtain. National census data and project data is available, but participants commented that this data was outdated. It also did not cover all aspects included in the model. A particular challenge in value chains is to find weekly or monthly data. Annual data is too aggregated to be of use in the simulation. On the other hand, much of the information obtained in the sessions was too detailed and specific to model. Additionally, participants were not always consistent in providing information. It is therefore important to have a clear boundary for what is being modelled and not, and at what aggregated level the model is being applied.

Different native languages between the main modeler and facilitator and the participants presented challenges, but the modeler was proficient in conversational Spanish and had several facilitators supporting her, as well as a person dedicated to note-taking. Access to a recorder was crucial in capturing the details of each GMB session, the progress made, and to document the entire process to assure recoverability. System dynamics also comes with its own technical terms and way of thinking. This was introduced in GMB2, partly using the storytelling function in iThink which worked well. Despite this, the SD language was perceived as difficult to understand by the producers. We found that setting aside enough time for the GMB participants to understand system dynamics, involving modelers with experience in interactive processes, and having a team of modelers and facilitators to share the different facilitation tasks was important to ensure participation and understanding among all, and to progress in co-creating a useful model.

GMB process results

The GMB process resulted in a conceptual model, shown in Figure 8, which focuses on the essential dynamic processes of the Matiguás dairy value chain. It is a qualitative model and provides an overview of the main modules in the model (herd, milk, feeds, and finance) and how they are interrelated (see Lie and Rich 2016 for further details). This provides a good foundation for understanding and discussing the model.

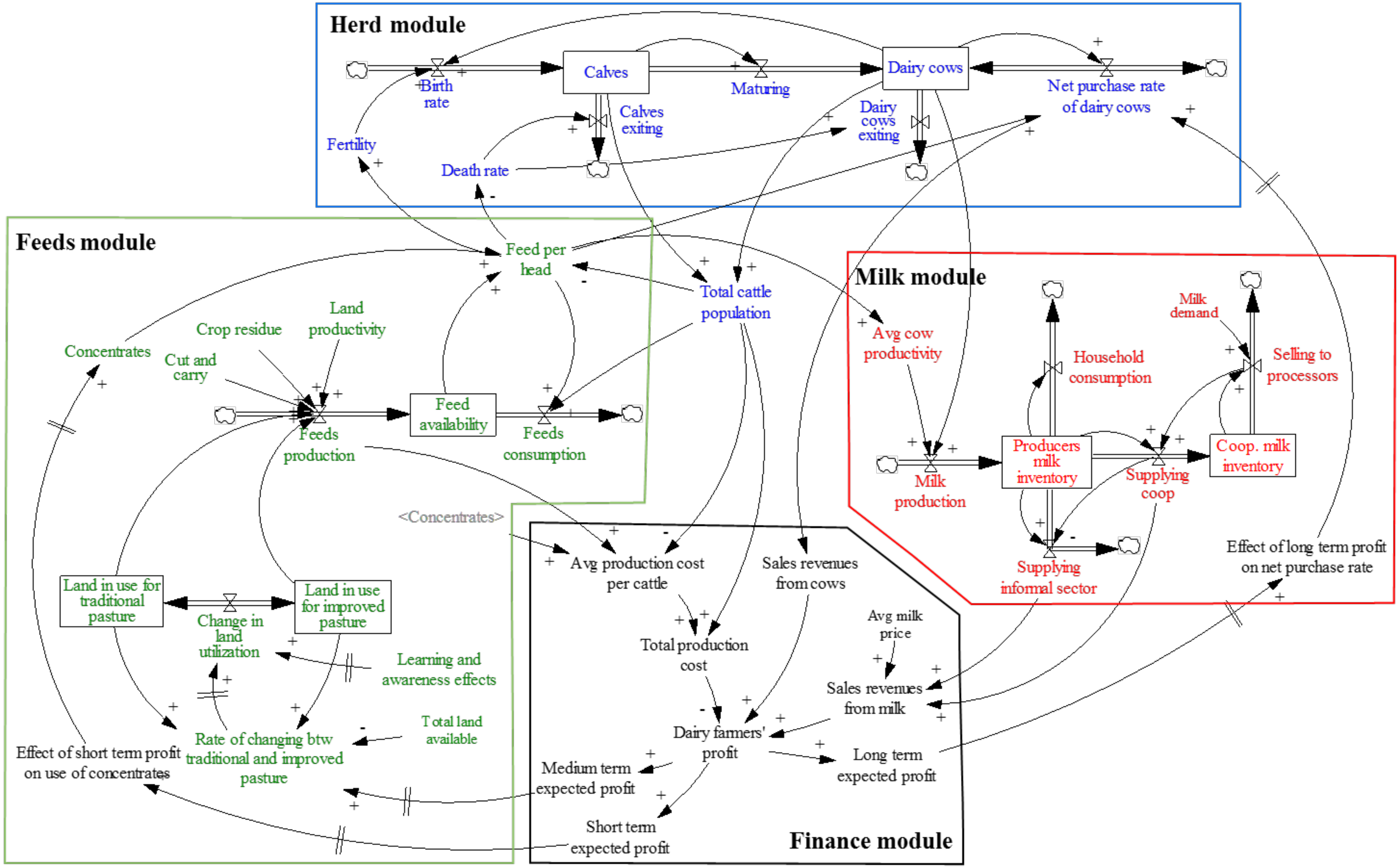

Figure 8: Conceptual system dynamics model of the Matiguás dairy value chain. Source: Modified from Lie and Rich (2016)

The primary output of the GMB process was the quantitative SD model. The model enables simulation of various scenarios over a ten-year period for the purpose of improving the small- and medium-sized farmers' feeding systems and increasing their income. An example of a typical scenario could be assessing the changes that occur in milk production and farmer profit if more land were to be allocated to improved pasture land. Scenario testing and sensitivity analysis of model results provide valuable information to policymakers and others working with dairy value chain development in Matiguás.

All participants in the GMB process and other interested persons can access the quantitative model online through isee Exchange[2]. (2) The model structure is presented step by step by using the storytelling function. Anyone can also run and compare various scenarios by changing key data in the model interface and see results in comparative graphs. This enables all users to actively interact with the model together or separately to support decision-making in value chain development.

The GMB process itself led to positive outcomes such as team learning, which is an important aspect of participatory research. The stakeholders participating in the process have strengthened their social capital by building closer ties with other actors from different nodes of the value chain. There is now a greater understanding and mutual appreciation of the roles played by different actors, the challenges they face in the value chain, and the importance of looking at the chain as an entity rather than through an individual perspective. One realization was that producers have limited understanding of the new quality-based pricing system and how the quality is determined. By improving interactions among stakeholders, our process potentially puts into motion a collective platform for them to place pressure on the industry to improve the dissemination of information about the pricing system. Small- and medium-scale producers, as well as the collection center and cooperative management, now also feel increasingly heard and know that their voice can matter in decision-making associated with interventions in the value chain. The interaction between the researchers and different stakeholders working in and with the value chain identified large data gaps. Closer interactions and discussions of problems, causes, consequences and potential solutions, plus having

[2] Available here: https://sims.iseesystems.com/helene-lie/dairy-value-chain-development-in-nicaragua

interactive tools to support them all in decision-making, benefits the value chain development process.

During the final session, GMB5, the participants wrote down what they had learned in an individual questionnaire. Seventy-five percent reported that the process had helped them "much" or "very much" to better understand the complex and dynamic processes in the Matiguás dairy value chain. Ninety-two percent stated that the process helped "much" or "very much" in identifying good interventions to improve the value chain, and 92% also indicated that they think this process will impact their future work. Despite the complexities of the SD model, 92% the participants reported "well" or "very well" that they understood the model, the results, and how it can be used. Several new stakeholders were introduced by the participants themselves since they found it interesting and thought their co-workers would as well. This indicates that participants were content with the process and are committed to using the SD model to support decision-making in value chain development.

Conclusion

The presentation of the participatory model building process of the Matiguás dairy value chain and its results illustrates its utility in value chain analysis. The participatory process enabled various value chain stakeholders to develop a deeper understanding of the complex and dynamic structure of the value chain, and how they perceive it differently. It offers a good alternative to the common top-down approach of collaboration among value chain stakeholders.

Co-creating the SD model enabled the participants to understand how the system dynamics model functions and can be used, but importantly to trust the model and its projections. The participatory model building process offered a good alternative to surveys for acquiring quantitative data in a non-extractive manner. Had the model been built on survey data, it would have been quickly outdated or not able to grasp the complexities, local practices, and decision-making logic of the dairy value chain actors.

The participants now have an online quantitative modeling platform that combines biological, agricultural, financial, and market aspects. It can be used to run scenarios on interventions in the short-, medium-, and long-run, providing valuable information for decision-making in value chain development. It is also possible to further develop the model to permit testing of other interventions, such as improved breeds.

The Matiguás experience illustrates that participatory SD modelling is time- and resource consuming. It is nonetheless critical for confidence building in and acceptance of the model among policymakers and others working with value chain development. It also illustrates the importance of carefully planning an iterative research design with specific emphasis on participant selection and procedures to ensure equal participation. Based on the experience in Nicaragua, participatory model building of value chains can be a powerful tool to support policymakers and other actors working with pro-poor value chain development in developing countries.

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ARTICLE 3

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Modeling Dynamic Processes in Smallholder Dairy Value Chains in Nicaragua: A System Dynamics Approach

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ABSTRACT

In Nicaragua, the production of dairy and beef is the most important source of household income for many smallholder producers. However, erratic volumes and quality of milk limit the participation of small- and medium-scale cattle farmers into higher-value dairy value chains. This research uses a system dynamics (SD) approach to analyze the Matiguás dairy value chain in Nicaragua. The paper presents the conceptual framework of the model and highlights the dynamic processes in the value chain, with a focus on improving feeding systems to achieve higher milk productivity and increased income for producers. The model was developed using a participatory group model building (GMB) technique to jointly conceptualize and validate the model with stakeholders.

Keywords. System dynamics; value chain; group model building; dairy; Nicaragua.

1 Introduction

In Nicaragua, the production of dairy and beef is the most important source of household income for many smallholder producers. However, several factors limit the participation of small- and medium-scale cattle farmers in dairy value chains. In particular, the quantity of milk produced by small-scale farmers is usually low, characterized by high seasonal fluctuations in availability and prices, with markedly reduced production levels during the dry season, and is often of poor quality (Holman 2014; MAGFOR 2013). However, due to low milk productivity, there is potential to increase the amount of milk produced, improve milk quality, and enhance the coordination among the involved actors to meet the increasing demand for milk (INIDE-MAGFOR 2013).

Recent research on value chains has noted the utility of system dynamics (SD) modeling in agricultural and livestock systems in analyzing the *ex-ante* impacts and potential feedbacks that can arise from different policy and technical interventions within the chain (Naziri et al. 2015; Rich et al. 2011). This research develops an SD model that represents the dairy value chain in Matiguás, Nicaragua to test potential areas of improvement, with a focus on the inclusion of small- and medium-scale cattle farmers. We focus on Matiguás as it is part of the largest milk producing area in Nicaragua, the 'Via lactea', that accounts for more than 20% of national production.

Three general research objectives were identified: (i) identify and explain the dynamic processes in the dairy value chain in Matiguás, Nicaragua, (ii) identify interventions, policies, and decision-making processes, and estimate their benefits and costs in the milk value chain by asking "what-if-questions", and (iii) discuss potential strategies/policies that can strengthen the competitiveness of small- and medium-scale dairy farmers in the milk value chain. This paper focuses on the first objective, while laying the foundation for answering objective two and three in future research.

The paper first provides background information on the dairy sector in Nicaragua and Matiguás. It then provides an overview of system dynamics and group model building, which are the methodological frameworks used. This is followed by presenting the elements of the model, including a description of the different modules in the conceptual model and its feedback loops. The paper ends with concluding remarks and a strategy for policy simulation and implementation.

2 Background: the dairy value chain in Matiguás, Nicaragua

Nicaragua is the second poorest country in Latin America and the Caribbean according to the World Bank (2014) with 43% of its population considered poor and the majority of them living in rural areas. Nicaragua is a relatively small country with 6.2 million people and a GDP of US$12 billion in 2014 (ibid). It is an agricultural country, with livestock contributing 13% of the national GDP and 45% of the national value of agricultural production in 2013. The Nicaraguan government has focused on improving the sector as it can contribute to poverty reduction, food security, economic development, and ecosystem restoration (MAGFOR 2013). In 2011, 51% of livestock keepers were classified as smallholders, defined based on landholdings of up to 14 ha, while another 37% are medium-scale producers with up to 70 ha (INIDE-MAGFOR 2011). National milk production has increased over the past five years, and was estimated at between 2 and 2.3 million liters per day in in 2012, with only 25% absorbed by formal processing plants. The informal sector processes the remaining quantity of milk (Holman 2014; MAGFOR 2013). Pasteurized dairy products are looked upon as one of the most promising economic sectors due to increase in production and exports as a result of growing demand from Central America and the USA (Polvorosa 2015). Despite the increase in dairy production, the sector faces many challenges in feeding, breeding, livestock management, infrastructure, and the environment. Each aspect has national strategies implemented through numerous partners within the Nicaraguan government, research institutions, private sector, and livestock farmers (MAGFOR 2013).

The Matiguás municipality, seen in figure 1, lies in the Matagalpa region 250 km away from the capital, Managua, and has a population of 42.300, where over 80% are livestock keeping households (INIDE-MAGFOR 2013). Dual-purpose cattle systems are the most common. Approximately 60% of milk producers in Matiguás are small-scale and 20% medium-scale producers (Polvorosa and Flores 2015). Small-scale producers typically own less than 14 ha of land, about 2-20 cows, and produce about 20 liters of milk per day. Medium-scale producers own between 14 to 70 ha, and produce around 50 liters/day. In total, about 100,000 liters is produced per day and most of the milk is collected through cooperatives. The largest dairy cooperative in Nicaragua, Nicacentro, is located in Matiguás (Polvorosa 2013). Matiguás is part of the "Via lactea" (or "milky way" in English), consisting of four municipalities, where over 20% of the country's milk is produced (INIDE-MAGFOR 2013). That is the main reason for the selection of this area of study.

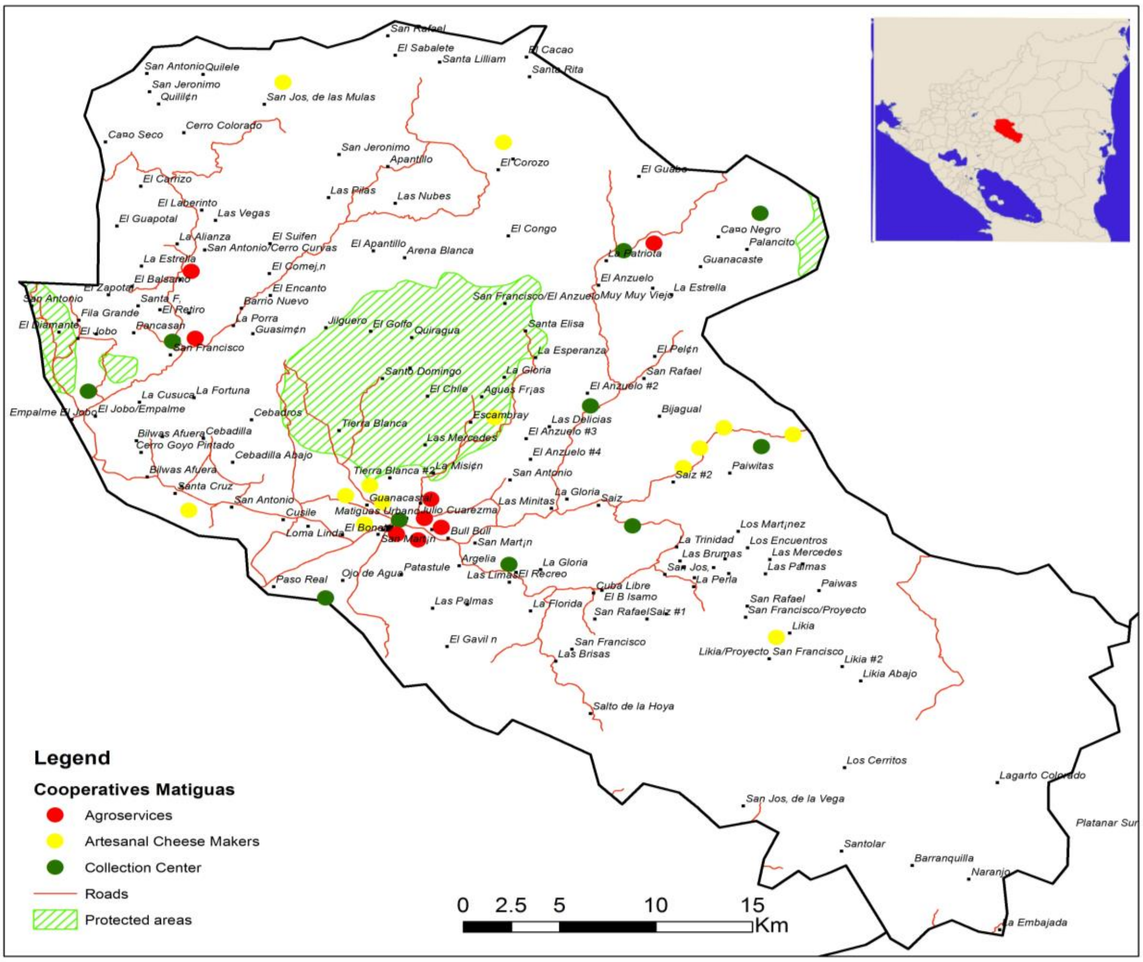

Figure 1. Map over Matiguás municipality Source: CIAT 2015

There are three main milk value chains in Matiguás highlighted in figure 2; (i) the cold milk chain where milk is collected by cooperatives and sold to the dairy industry in Managua, (ii) informal local curd processing for consumption and sale locally, and (iii) collection of milk that is processed into fresh cheese and exported to neighboring countries (Alcaldía Municipal de Matiguás 2011; Polvorosa 2013). There is competition between the chains in attracting milk suppliers (Polvorosa and Flores 2015). This research focuses on the cold milk chain. In the cold milk chain in Matiguás, five cooperatives and several private actors collect milk from more than 1000 producers in over 14 collection centers. Of those supplying collection centers, about 70% of milk producers are organized in a cooperative, whose milk is supplied to the three milk processors in Managua (Lala, Nilac, Centrolac) (Alcaldía Municipal de Matiguás 2011; Polvorosa 2013)

Several value chain analyses (VCA) of the dairy sector in Matiguás have been conducted by various institutions such as International Center for Tropical Agriculture (CIAT), HEIFER, the research and development institute Nitlapan, and Tropical Agricultural Research and Higher Education Center (CATIE). They all present a structure of the stakeholders involved, product flows (see figure 2), and identify numerous interventions to improve various areas of the chain (Flores et al. 2011; Polvorosa 2013; Velásquez and Manzanarez 2014). The Municipal government (Alcaldía Municipal de Matiguás 2011) have also made their local economic development plan which include focus on the dairy value chain.

The main challenges identified in the Matiguás dairy value chain are aligned with the national challenges. In Matiguás and 'Via lactea', there is potential to increase the amount of milk produced, improve milk quality, and enhance coordination among the involved actors. The current increase in milk production is primarily due to an increase in number of animals and using more land for livestock purposes. However, land availability is close to reaching its limits, thus forcing other strategies for increased and stable milk production. Stabilizing the volume of milk during the year and improving the productivity of animals are two of the biggest challenges, especially since there is little room to continue to expand land use for livestock purposes. There is also underutilized capacity of collection centers, especially during the dry season from January to mid-May (Alcaldía Municipal de Matiguás 2011). Despite several value chain analyses and plans, none presents any justified forecast of potential impact if any or all of the identified interventions were implemented. This suggests a need for methodologies that can better evaluate the returns to alternative investment strategies.

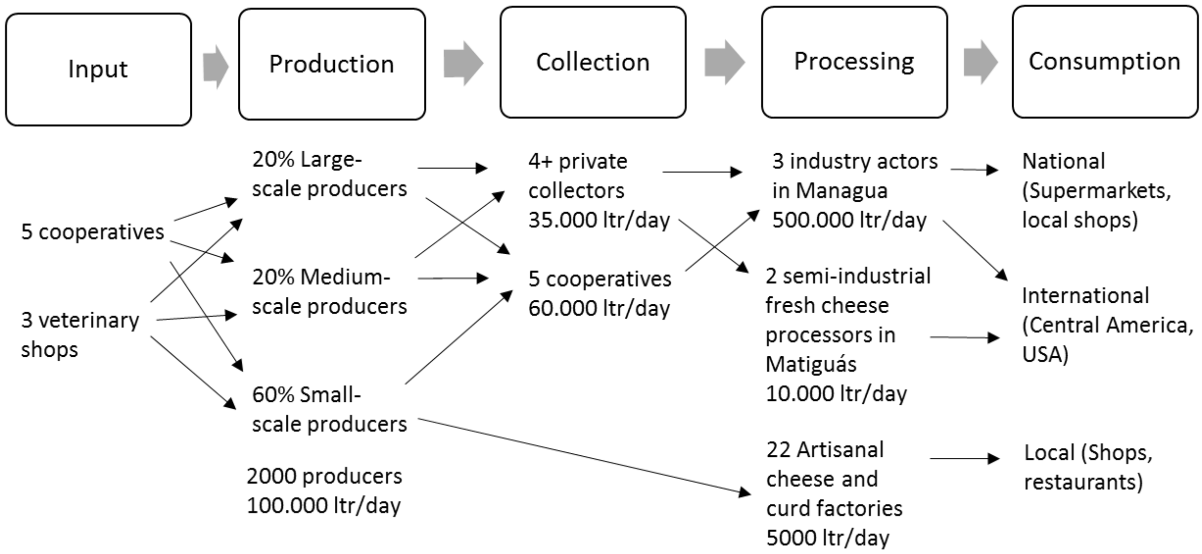

Figure 2. The Matiguás dairy value chain. Source: Modified and updated from Polvorosa and Flores (2015); Velásquez and Manzanarez (2014)

3 Methodology

Value chain analyses (VCA) provide an overview of the actors, their activities, and flows of commodities, money and information and can identify challenges and suggest interventions (Kaplinsky and Morris 2001; M4P 2008). However, an important challenge and limitation of VCA and value chain toolkits is that the results are highly qualitative. In particular, it is difficult to know or predict *ex-ante* what impact or outcomes that different interventions might have within these complex systems (Rich et al. 2011). As the introduction of new interventions will cause changes in both marketing and contextual features of the value chain, various unintended consequences or feedback mechanisms may result that could undermine or reduce the effectiveness of an intervention over time.

System dynamics methods are one means to address these gaps in value chain analysis. A system dynamics (or SD) model maps out the flows, processes, and relationships between actors that operate within a complex system. It is highly interdisciplinary and can be used as a tool to test and analyze interventions and policies (Sterman 2000). Recent research on value chains has noted the utility of this approach in agricultural and livestock systems in testing out the *ex-ante* impacts of feedbacks from different policy and technical interventions within the chain (Higgins et al. 2009; Naziri et al. 2015; Rich et al. 2011).

The central concepts in SD models are stocks, flows, and feedback loops. Stocks represent the accumulation of something, for example animals or an agricultural product. Flows, or rates of change in variables, are used to change the levels of stocks. Feedback loops are a type of circular causality where one component in the model initiates changes in another component, which further initiates changes that result in various outcomes. Feedback loops can either be positive, meaning that they are self-reinforcing, or negative which means they are self-correcting (Sterman 2000). The goal is to build an SD model that represents, in this case, a value chain and its dynamic processes. The SD model can be qualitative, also called mental maps, or quantitative which enables testing of scenarios through running simulations (Sterman 2000).

A particular advantage of system dynamics models is that they can be conceived and developed through participatory processes. In particular, many analysts use what is known as group model building, or GMB, to develop their models jointly with the participation and direct collaboration of stakeholders (Hovmand 2014; Vennix 1996). The data collection for this research was conducted in Matiguás from March to June 2015 utilizing group model building principles.

The use of GMB to develop SD models is important when it is difficult to grasp the comprehensive and complex systems involved, when there are many different alternative value chain interventions, and difficult to anticipate the possible consequences of a decision made (Vennix 1996). It is also important when there are many stakeholders involved. It is a good tool for building consensus and commitment to the final chosen strategy since all stakeholders are involved in constructing the model, testing suggested interventions and policies, and making final decisions. It can also bring together stakeholders, with very different backgrounds and focus, which often is the case in developing country settings. These people sometimes do not meet, or often meet separately, but discuss the same issues. It can uncover different attitudes and understandings among the participants during the process of making the model in the group (e.g. Olabisi 2010). This can itself create a better environment for future collaboration with a better understanding of how the different actors work, and connection among them. It can also help facilitate buy-in by stakeholders in development projects and assure sustainability after the end of a project (Hovmand et al. 2011; Vennix 1996).

A participatory SD modeling process starts with problem identification and articulation to decide on a clear purpose that guides the entire modeling process. It is important to agree on what problem to focus on, to understand why it is a problem, and to create a reference mode of the overall problem behavior. The system is then conceptualized by identifying different elements in the system and how they are related, and determining the boundary of the model. This leads to formulating dynamic hypotheses or theories about the causes of the problem. Some modeling processes focuses on qualitative conceptual models. If so, the modeling process would end here. If a quantitative approach is taken, the process continues with model formulation by estimating parameters, followed by model evaluation and testing. The model is then ready for analysis to develop policy recommendations, as well as transferring the insights to different stakeholders in the value chain. The final step is to assess the process and outcomes of the modeling exercise. (Luna-Reyes et al. 2006; Sterman 2000; Vennix 1996). The value chain stakeholders are included in the entire process, and there exists numerous ways to facilitate the participation (Hovmand 2015), which needs to be carefully considered before and during the modeling process to ensure participation of all stakeholders.

This research paid careful attention to include the various stakeholders in the complex Matiguás dairy value chain, but focused on small- and medium-scale dairy farmers. Between March and June 2015, four main group meetings were conducted with small- and medium-scale dairy farmers, dairy cooperatives, local institutions focusing on credit, research, farmers' schools, local government, and the informal dairy sector. In April 2016, a follow-up group meeting was conducted. The group meetings focused on identifying a value chain goal, problems in reaching the goal, prioritizing which problem to focus on, possible interventions, model structure, and necessary parameters and relationships for the model. In addition, reference group meetings with research institutions were organized in between focusing on verifying the model structure and data. A scoping trip was conducted before the meetings and selection of participants to have a basic understanding of the dairy value chain and its stakeholders that needed to be involved in the modeling process. Several individual interviews with cooperatives, credit institutions, and industry actors were conducted during and after the group process to complement and verify some of the information given in the group.

4.1 Model focus

The first group model building session identified the top policy goal as increasing the production of milk, both in terms of quality and quantity, to achieve higher income for the actors that are involved in the value chain. During the same session, a discussion on the problems in achieving this revealed that the deficient feeding system should be the priority focus for this SD model. We thus focus on identifying policies and investments that could enhance the quality of feeding systems in a manner that can improve milk quantity and farm income.

In Nicaragua, milk production follows a cyclical pattern due to fluctuating rainfall patterns. Low production volumes occur in the dry season, from approximately January to mid-May, with higher volumes occurring during the rainy season from mid-May to December. Approximately 65% of annual production is realized in the wet season (Polvorosa 2015). An important objective for small- and medium-scale producers in particular is to find ways to stabilize milk production during the year as a way of improving year-round market access and thus achieve more stable incomes from milk. One of four main factors pointed out to achieve this is to substitute traditional pasture with improved pasture. Other factors identified included increasing herd sizes by replacing male cattle for female cattle; ensuring sufficient labor to manage the herd, especially during milking; and introducing improved hygienic milking practices (Polvorosa 2015; Polvorosa and Flores 2015).

Using improved pasture is a common and important practice to intensify milk production. Improved pastures have positive impacts on milk production per animal and per unit area, thus reducing production costs and raising net income for livestock producers. It is also more resistant to erratic weather such as drought (Holmann et al. 2009). The percentage of farmers with improved pasture has increased in

Matiguás over the past ten years, but the proportion of land devoted to forage has declined. Several factors explain this, including new land used for livestock, and the high establishment costs of improved pasture that results in farmers only using a small portion of land to create forage banks (Polvorosa 2015).

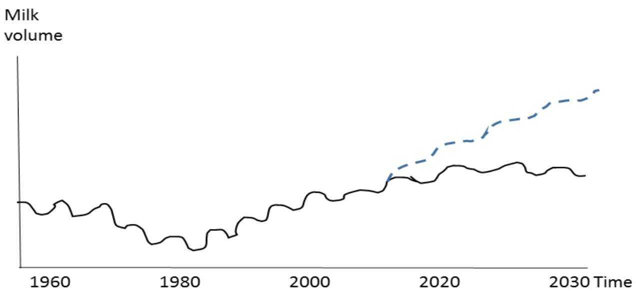

Figure 3. Milk production trends over time. Source: Developed by the authors

The first GMB session also developed a reference mode, illustrated in figure 3, which highlights the historic trends of milk production and forecasts about future trends with and without any interventions. In the 1960s, milk production was quite low, and worsened during the 1980s. Since the 1990s, there have been gradual improvements to the sector, but growth has been relatively slow. However, in the absence of interventions, limited land availability will eventually mitigate any increase in milk production. The oscillations found in figure 3 represent the annual seasonal swings in milk production during the year. The dotted line indicates predicted milk production with potential interventions that improve the feeding systems for small- and medium-scale producers. In addition to increasing milk production, the expectation is that yearly oscillations would be smaller, although natural seasonal variation will always occur. The research questions below guided the model conceptualization.

1) What feed type, or combination of feed types (traditional pasture, improved pasture, cut and carry, and concentrates), provide higher productivity of milk during the year, especially during the dry months?
2) What is the effect of changing feeding systems on the income of small- and medium-scale producers over the short-, medium- and long-term?

4.2 Model structure

We present the conceptual model developed in conjunction with stakeholders in figure 8. The model consists of four main modules: 1) herd dynamics, 2) milk processing and sales, 3) costs and revenues, and 4) feed dynamics. Each section will be explained before presenting the dynamic interactions between the different modules. The model was constructed using the model software Vensim PLE Plus[1].

Herd dynamics

The herd dynamic module consists of two stocks of calves and dairy cows, represented by the rectangular shapes in figure 4, that are mediated by biological processes of births, maturation, and exits (either by death or sales). We also consider outflows a separate bi-flow denoting the net purchasing rate of dairy cows, since farmers will decide to sell or purchase more dairy cows depending on the amount of feed per cow and the level of long-term profit (indicated by shadow variables from the other modules). If feed per cow is low over time, we assume that farmers will sell dairy cows, while if there is high home grown feed availability per cow over time, we assume they will buy high productive dairy cows to add to their herd. This decision also depends on whether realized long-term profits are higher than expected over time. If so, we assume that farmers will buy dairy cows, while negative profits relative to expectations would induce sales. There is a link from dairy cows to the birth rate to model the reproduction of animals based on the fertility rate. Fertility and death rate are influenced by feed per head.

[1] Available at: http://vensim.com/

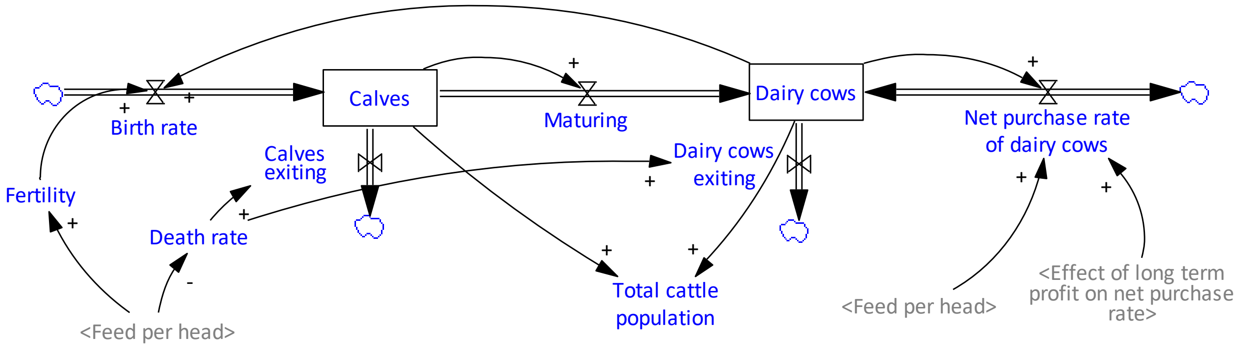

Figure 4. Herd dynamics module. Source: Developed by the authors.

Milk processing and sales

The milk flow module, shown in figure 5, illustrates the downstream activities in the dairy value chain in Matiguás municipality. We model the production of milk as influenced by the number of dairy cows and average cow productivity. Cow productivity is affected by feed per head and assumed rates of disease incidence. Producers have several options with which to supply, in addition to deciding how much milk to consume at home. In particular, farmers can choose to supply to one of the five major cooperatives, or can supply the informal sector through private milk collectors (or a combination). The cooperative supplies the five industrial processors in Managua, whose production depends on the demand for milk.

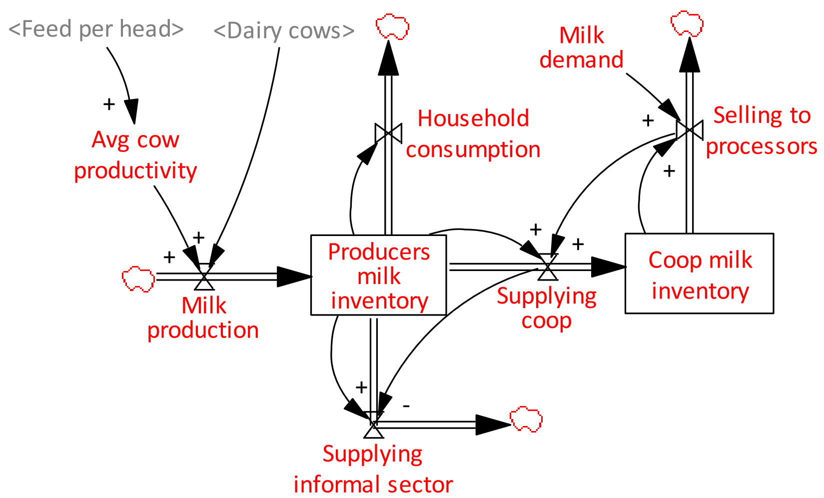

Figure 5. Milk sale and processing module. Source: Developed by the authors

Costs and revenues

The costs and revenues module, presented in figure 6, only consists of variables. The main variable is dairy farmer profit that results from revenues from milk and cow sales, and production costs. Revenues from milk sales include the total amount of milk supplied to cooperatives and informal sector multiplied by the average milk price. For simplicity, we consider only one average milk price, but in reality the milk price varies between the cooperative and the informal sector. We assume that price is an exogenous variable since it is unlikely that dairy producers in a municipality will heavily influence the milk prices set by industry actors in the capital. Even though we model prices exogenously, we assume that the milk price fluctuates seasonally. Total production costs depend on the average production cost per head of cattle and the total cattle population. For simplicity, we assume that average production costs per cattle include costs for feed production and concentrates, and other production costs such as labor, medicines, water, electricity, and so on.

Profits higher than expected induce farmers to make investments in both short-, medium- and long-term activities. In other words, we assume that different investments are endogenously determined in the model based on the level of expected profits (short-term, medium-term, long-term) and are not made independently. If profits are higher than expected in the short term, we assume that farmers invest in feeding their cattle concentrates, which is explained further below. If profits are higher than expected in the medium term, we assume that farmers will invest in improved pasture, which as discussed below changes the allocation of land towards more productive feed sources. Higher profits than expected over a longer time period leads to buying dairy cows, given that there is enough feed available to increase the herd. All of these investments occur with a delay since it takes time for farmers to make a decision, as well as completing the activity of changing their feeding system or purchasing a cow, which is indicated with a double line on the connecting arrow.

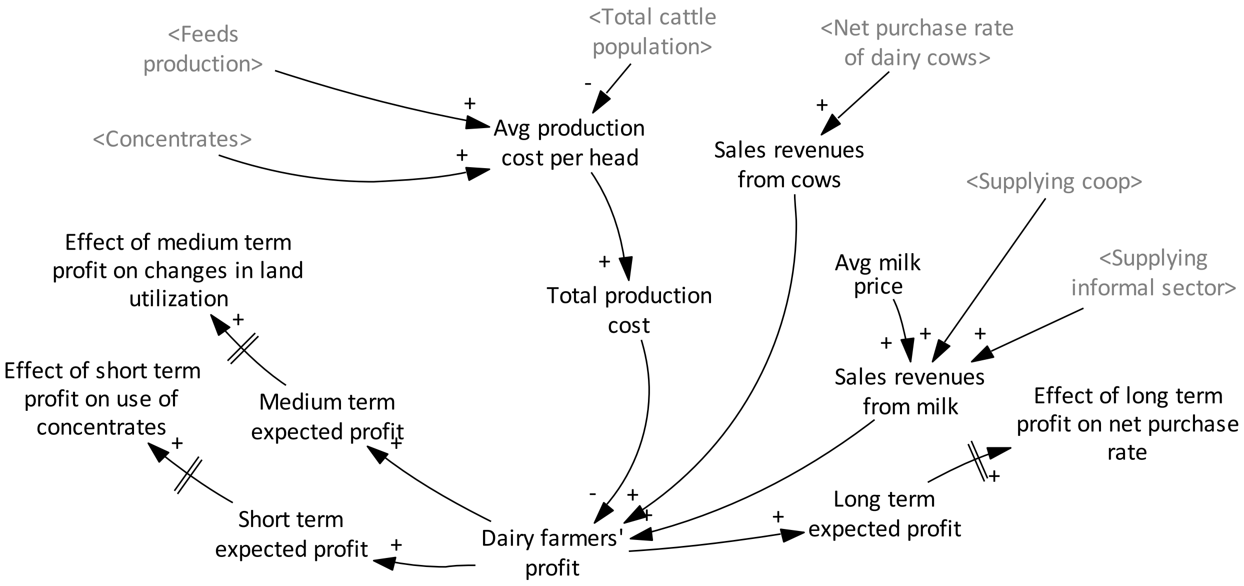

Figure 6. Cost and revenue dynamics. Source: Developed by the authors.

Feed dynamics

The feeds module consists of a stock that denotes home grown feed availability. Home grown feed availability increases through greater production and falls from the consumption of feed; these are denoted as inflows and outflows, respectively. Feed production is based on a combination of cut and carry grasses, traditional pasture, and improved pasture. We assume that the amount of land used for cut and carry grasses in this model is fixed, so that farms choose to allocate their remaining land area (also fixed in aggregate) between traditional and improved

pasture. Buying land is not included due to limited land availablility, hence our focus on intensification. We assume that each of the four feed production options have their own level of production yield (aggregated for simplicity in figure 7 as land productivity). Land productivity also depends on whether there is drought or not. The land allocation decision process depends on investments in feed, which is determined by the medium-term profitability of farmers. Changes in land utilization are also influenced by other factors. In particular, peer effects, learning, and awareness could influence perceptions and proclivities towards changing land use, although these could both happen with a delay and impose transactions costs on producers.

The reason to invest in improved feeds and concentrates is to increase the total availability of feed and thus improve average cow productivity, or the ability to keep more cows. Changing feed production adds to production costs, and whether the investment is profitable or not, depends on how much the investment in improved feeds production influences the average cow productivity. Feed per head is determined by the amount of available feed divided by the total cattle population. The use of concentrates can complement feed per head, which depends on short-term profitability.

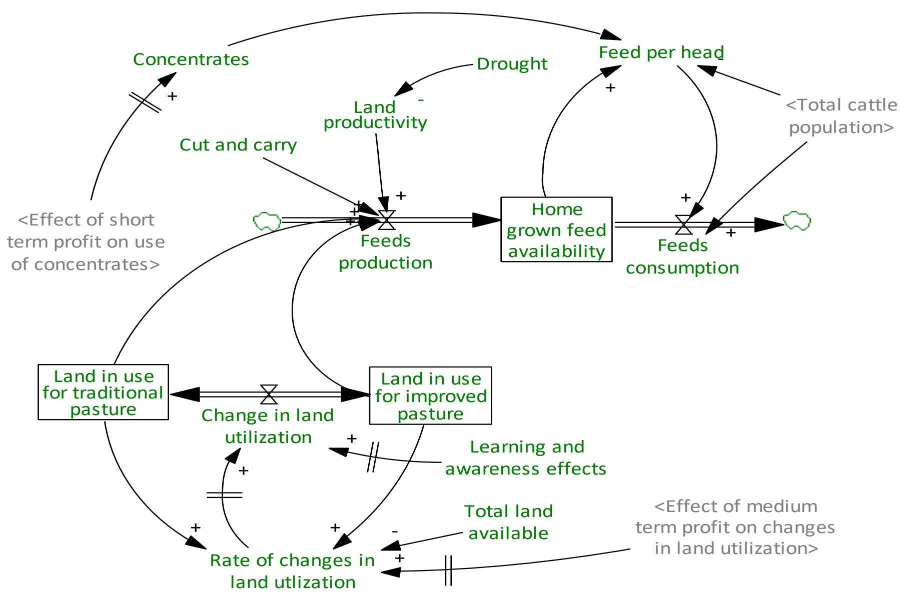

Figure 7. Feed dynamics module. Source: Developed by the authors.

4.3 Feedback loops between the four modules

The four main model modules interact through feedback loops that denote the dynamic processes in the dairy value chain. If a decision is made to invest in improved feeds, it will have implications both for herd dynamics and milk processing and sales. Following standard SD terminology, feedback loops can either be reinforcing (with exponential growth or decay) or balancing (settling on some level of stasis or equilibrium). A few of the different reinforcing and balancing feedback loops have been identified and marked with an R or B, respectively, in the conceptual model in figure 8 and are briefly explained in table 1 below.

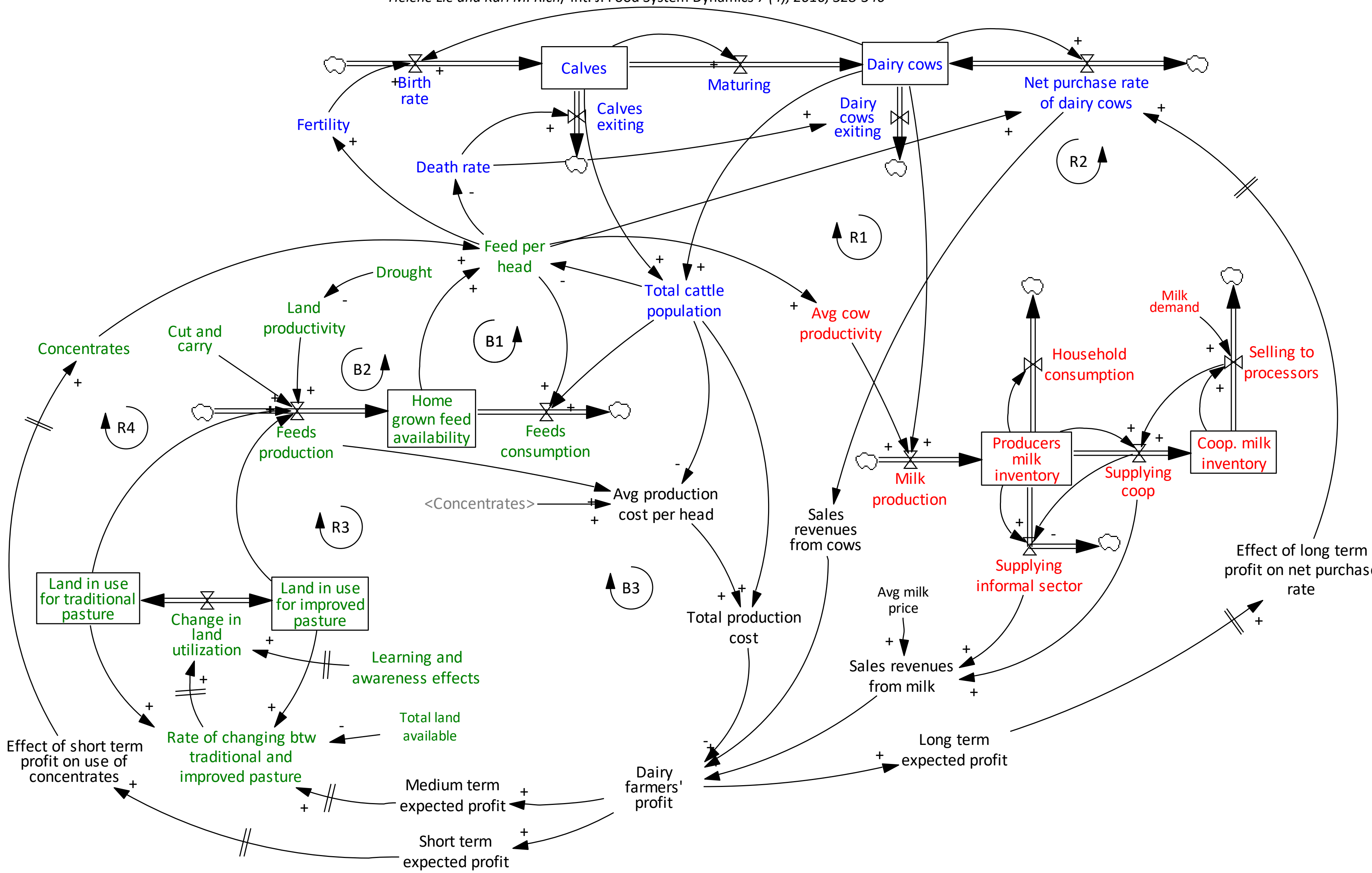

Figure 8. Conceptual SD model of the Matiguás dairy value chain. Source: Developed by the authors.

Table 1.
Overview and short explanation of feedback loops. Source: Developed by authors.

Feedback loop	Explanation
R1	This reinforcing feedback loop focuses on the relationship between increasing the number of dairy cows, which increases the amount of milk produced, thus increasing profits that are used to invest in improved feeds/concentrates, improving fertility and reducing death rates and therefore increasing the number of dairy cows.
R2	This feedback is similar to R1, but focuses on long term investments in additional dairy cows.
R3	This feedback loop focuses on the increasing land used for improved pasture, which has a positive effect on home grown feed availability leading to increasing average cow productivity, which increases milk production and milk supply. This then increases revenues and medium-term profit, allowing for investments in improved pasture that again improves feed production.
R4	This feedback loop is similar to R3 but focuses on short-term investment in the use of concentrates in the dry months, which increases the milk production and short-term farm profit.
B1	This balancing feedback loop focuses on the impact of increasing the number of dairy cows on feed use per head. More dairy cows reduce feed use per head, lowering average milk productivity and decreasing milk production. Consequently, farm profits fall, reducing investments in concentrate in the short-term and leading to dairy cow sales in the long run, which will reduce the number of cattle and increase the feeds per head.
B2	This balancing feedback loop highlights that if drought occurs, land productivity falls. This negatively affects home grown feed availability, which reduces the quantity of feed per head of cattle.
B3	This feedback loop focuses on the costs of feed production, which will increase when adopting improved pasture and/or use of concentrates. This will impact total production costs, farm profits, and subsequent investment decisions.

The four explicitly identified reinforcing feedback loops will increase milk productivity and farm profit exponentially. This growth is, however, counteracted by the various balancing loops in the model, that given biological and investment delays lead to the oscillatory behavioral patterns highlighted in figure 3. While R1 and R2 increase the number of dairy cows, this growth is balanced by B1 because if the number of dairy cows increases, the amount of feed per head will go down, leading to a reduction in milk production. Feed per head is also vulnerable to climatic changes such as drought, B2, which result in reduced land productivity. These two balancing feedback loops will slow down cow productivity and reduce the growth of milk production. That means the exponential growth in the beginning will be corrected and result in an s-shaped growth pattern.

Similarly, R3 and R4 will both result in an increase in the amount of feed per head of cattle, which positively affects cow productivity and results in the exponential growth of milk production and subsequently in farmers' profit. However, B3 counteracts and places a brake on such growth in profits, as investments in improved pasture and use of concentrate raise the average production cost per cattle and reduce profits.

With several reinforcing and balancing feedback loops, such as in this complex dairy value chain, it is difficult to predict the changes in the system and its subsequent changes in farm decisions. The effects and changes will also be different over the short-, medium- and long-term. As a consequence, transforming our qualitative structure into a quantitative SD model allows us to examine various scenarios that can be simulated over time (Sterman 2000). While some changes are easy to anticipate, other unintended consequences can also appear when running different scenarios in a quantitative model. This is an area for future work with this framework, where we will test different scenarios and hypotheses in a quantitative setting.

5 Concluding remarks

The dairy sector in Nicaragua faces several challenges, with feed availability being a crucial constraint. A system dynamics approach was taken to identify the dynamic process in the dairy value chain to be able to assess intervention options and their potential effects on milk quantity and farm income. In this paper, the conceptual system dynamics model was presented in detail including the dynamic processes between herd dynamics, milk processing and sales, costs and revenues, and feed dynamics. Future research will highlight the impact of different scenarios and hypotheses focusing on aspects such as (i) increasing the number of dairy cows, (ii) increasing the use of concentrates in the dry months, and (iii) increasing land used for improved pasture. These will support decision-making among the various stakeholders in the Matiguás dairy value chain to add value and raise incomes for stakeholders.

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ARTICLE 4

Quantifying and evaluating policy options for inclusive dairy value chain development in Nicaragua: A system dynamics approach

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Abstract

Achieving inclusive value chain development is a challenging task due to the complex and dynamic nature of interconnected value chains and their social, economic, and ecological context. While many policies and intervention options exist to upgrade value chains, there are fewer methods that can be used to understand and quantify the multidimensional impacts that value chain policies and interventions may have throughout the value chain. This paper addresses this methodological gap by employing a system dynamics (SD) modeling approach. SD models allow us to model and quantify the processes and relationships inherent in the value chain through simulations, serving as a policy laboratory for the empirical assessment of intervention options. An SD model of the Matiguás dairy value chain was constructed and tested through a participatory modeling process. Our research tested and evaluated the short-, medium-, and long-term impacts of specific interventions and policies in the Matiguás dairy value chain with the goal of strengthening the competitiveness and inclusion of small- and medium-scale producers. These interventions revolved around improving the feeding system, which was identified by stakeholders in the Matiguás value chain as the critical constraint to competitiveness. The policy analysis reveals that both improved pastures and increased use of concentrates raise producer milk productivity by5 and 11% respectively in the long run, but are also expensive strategies for smallholder producers, leading to a reduction in profits by 1% and 3%, respectively. Policy makers should identify strategies that help to reduce concentrate costs and support producers with investments in improved pasture, while at the same time promote training in pasture management skills. In the long-run, investment and training in pasture management results in a 30% and 35% increase in milk production during the wet and dry season, respectively. Simulation results further highlighted that intensification of the feeding system to improve cow milk yields is mainly profitable in the long term, and thus requires a longer term perspective by policy makers. The model provides a deeper understanding of the complex and dynamic nature of the Matiguás dairy value chain and the interactions between markets, coordination aspects, biophysical phenomena, and income. The system dynamics approach to value chain analysis further addresses a major analytical shortcoming in value chain analysis and provides decision makers with an improved platform for planning and policy formulation.

Highlights

- Dairy farmers in Matiguás face feed system constraints that reduce competitiveness
- Conventional value chain methods are unsuited to prioritize upgrading options
- System dynamics (SD) methods were used to quantify policy impacts
- Combining extension with improved pastures yield the highest return for farmers
- SD modeling helps decision makers with planning and policy formulation

Key words: System dynamics; value chain analysis; inclusive development; policy analysis; smallholders; dairy

1. Introduction

The transformation of the global agrifood system offers opportunities, and poses challenges, for the integration of smallholder farmers into remunerative local, regional, and global markets. The demand for higher-value agricultural products is growing, in both developing countries and foreign markets due to a constellation of interrelated trends associated with urbanization, higher incomes, and changing food preferences away from staple goods and towards value-added, and protein-rich foods (Arias et al. 2013; IFPRI 2017). Connecting smallholders to such markets, whether local or global, could be an effective way of reducing poverty and improving food security in developing countries.

However, smallholder farmers, and particularly poor rural farmers, are often excluded from these increasingly complex and dynamic markets (IFPRI 2017). Commercial markets are highly competitive, with high quality standards and requirements of consistent, timely deliveries (CFS 2015; Devaux et al. 2016). Due to limited access to land, capital and information, often exacerbated by poor infrastructure, many smallholder farmers have limited contacts with commercial markets and hence a poor ability to react to market forces (Devaux et al. 2016). .

In Nicaragua, the cattle sector, including dairy, is economically and culturally important, and 90% of farmers are small- and medium-scale. With the rapid commercialization of the dairy sector, their inclusion is an important policy issue (MAGFOR 2013) and ensuring their competitiveness is vital. In the municipality of Matiguás, located in central Nicaragua, 80% of households keep cattle, the most important source of household income. Through cooperatives, some farmers have access to formal markets, but ensuring steady milk quality and quantity, the latter especially in the dry season, poses challenges for successful market participation (Alcaldía Municipal de Matiguás 2011; Velásquez & Manzanarez 2014). Policy and intervention options include promoting investment in improved pasture, investing in improved breeds, increasing the use of concentrates, or improving the coordination between nodes in the chain. However, the returns and dynamic effects of such options are not obvious, limiting the ability of value chain actors, donors, and policy decision makers to sustainably engage in investing in value chains.

As the Matiguás case exemplifies, value chains consist of social, economic, and ecological systems that are highly interconnected. If one part of the system faces challenges, such as power asymmetry, price shocks, or extreme weather, other sub-systems and their participants will be impacted accordingly. The unintended effects of well-intended value chain interventions are often not considered, leading to dysfunctions, for instance when trying to combat some of the challenges facing smallholders.

Value chains in developing countries need to be inclusive, i.e., ensuring participation of vulnerable social groups, such as smallholders (Helmsing & Vellema 2011), and emphasizing social as well as economic goals. The value chain analysis (VCA) framework provides an interdisciplinary, structured, yet flexible approach to facilitate inclusive value chain development, but understanding and quantifying the multidimensional impacts of value chain interventions throughout the value chain still constitutes an important research gap.

In this paper, we seek to address this gap generally and in the context of dairy in Matiguás by employing a methodological perspective that allows us to model and quantify the processes and relationships inherent in the value chain. Using a simulation approach, this perspective serves as a policy laboratory for the assessment of intervention options. Our research specifically aims to test and evaluate the short-, medium-, and long-term impacts of specific interventions and policies in the Matiguás dairy value chain with the goal of strengthening the competitiveness and inclusion of small- and medium-scale producers. We employ system dynamics (SD) modeling to explicitly map the information and material flows, processes, decision rules, and relationships between actors that operate within a complex value chain system (Sterman 2000). Recent research has revealed the utility of this approach in agricultural and livestock systems to *ex-ante* test the dynamic impacts of feedbacks from different policy and technical interventions within value chains (Naziri et al. 2015; Rich et al. 2011). An additional advantage of SD modeling is the ability to employ participatory processes in the design, construction, parameterization, and application of value chain models, improving validity and engaging value chain actors together in a process of joint learning (Lie et al. 2017). This approach thus addresses a major analytical shortcoming in traditional VCA and provides decision makers with an improved platform for planning and policy formulation.

2. Background: Dairy production in Nicaragua and Matiguás

In Nicaragua, livestock production represents 45% of national agricultural GDP and 32% of exports by commodity value. Daily milk production averages 2-2.5 million kg, of which half is processed by the formal sector, the remainder being absorbed via informal channels. The sector's size and potential (e.g., for export of dairy products to other Central American countries and the USA) is important for the Nicaraguan government, for its contribution to food and nutritional security, income generation, economic development, and ecosystem restoration (Holmann 2014; MAGFOR 2013).

Of the 80% of the households in Matiguás keeping cattle, 60% are small-scale producers owning less than 20 mz[1] of land, two to 20 cows and producing about 20 kg of milk per day. Medium-scale producers make up 20% of the cattle-owning population, own between 20 and 100 mz of land and produce about 50 kg of milk per day (Polvorosa & Flores 2015). The growing commercialized dairy industry threatens the participation of small- and medium-scale producers in formal markets, increasing their dependency on the informal dairy sector with unstable milk prices (INIDE-MAGFOR 2013). Therefore, small- and medium-scale producers need to find ways to ensure their competitiveness alongside larger producers.

Dairy cooperatives collect milk and provide support to producers in the form of access to inputs, credit, and extension services. In Matiguás the dairy value chain includes five cooperatives that collect milk from over 1,000 producers (Polvorosa 2013). About 100,000 kg of milk are produced every day, of which 60% is collected by cooperatives. The dairy industry based in the capital Managua controls the conditions of participation in the formal dairy value chain (Polvorosa 2013). See Lie and Rich (2016) for a value chain map for the Matiguás dairy sector.

The value chain faces challenges in the seasonality of milk production, difficulties in securing high quality milk, and the variation in milk prices and demand for milk (Alcaldía Municipal de Matiguás 2011). Several institutions aim to support and promote inclusive development in the dairy value chain in Matiguás and have suggested a number of policies and interventions to mitigate the challenges after conducting value chain analyses (e.g., see Alcaldía Municipal de Matiguás 2011; Johan Bastiaensen et al. 2015; Velásquez & Manzanarez 2014). These include improving coordination among the actors in the chain through better information and communication regarding the newly introduced quality-based pricing system for milk; improving cattle breeds; and promoting the use of improved pastures and concentrates that reduce seasonal variations among small- and medium-scale producers. However, value chain

[1] In Nicaragua land is measured in manzanas. 1 mz = 0.7 ha. Small-scale farmers a own less than 14 ha, medium-scale farmers between 14 and 70 ha, and large-scale more than 70 ha of land.

analyses and plans have not included an economic assessment of potential impact of these interventions.

3. Materials and methods

3.1 Applying system dynamics modeling in value chain analysis

Value chain analysis (VCA) is a useful framework to diagnose ways to improve agricultural value chains and facilitate the inclusion of smallholders. It is an interdisciplinary, structured, yet flexible framework that provides context to the inner workings of complex value chains. VCA provides a narrative of value chain characteristics. It first provides a *mapping* of the flow of products, services, information, volumes, and value added in the chain, as well as the actors and the relationships between them, and provides detail information about the activities in the chain. Second, VCA addresses *governance* mechanisms that define how and who coordinates chain activities, and factors that influence transaction modes. VCA identifies opportunities to *upgrade* the chain, "a positive or desirable change in chain participation that enhances rewards and/or reduces the exposure to risks" (Riisgaard et al. 2008: 7). Upgrading can address the means to improve or develop new products, improve the efficiency of chain processes (e.g., ensuring timely deliveries, collection of quality produce, or improved marketing), highlight new opportunities for value-adding in different chain functions, or identify new, more profitable chains altogether. Finally, VCA attempts to measure the *distribution of benefits* by analyzing who gains and who loses in the value chain. The implementation of VCA by practitioners has been facilitated by the development of various handbooks that guide the value chain development process (e.g. see GIZ 2008; Kaplinsky & Morris 2001; Terrillon & Smet 2011; World Vision 2016).

Despite the utility of value chain analysis, a number of drawbacks remain (Rich et al. 2011). First, while VCA identifies bottlenecks in the chain and suggests ways to address them, it offers little evidence-based empirical guidance to assess the intended and unintended up- and downstream effects associated with the implementation of recommended policies or interventions. Likewise, conventional methods make it difficult to evaluate the impacts of different policies on different actors in the chain, and over the short- or long-run. Indeed, each node in the chain itself represents a complex and dynamic sub-system that needs to be mapped, analyzed, and quantified individually and in relation to the rest of the chain to capture the dynamic effects associated with policy change.

SD modeling enables this type of visualization and analysis. SD is a computer-aided approach to policy analysis and design. SD models can be qualitative or quantitative. Qualitative SD models can be used to map a complex system such as a value chain, and highlight the structure of the system and its behavioral drivers. Qualitative models can also provide insights on feedback structures that drive system change (McGarvey & Hannon 2004). Quantitative SD model parameterize this structure with empirical data, enabling the use of computer simulation to test different scenarios. In a value chain context, simulation can quantify the effects of different types of potential upgrading strategies, and provide dynamic insights across the chain and amongst different chain actors (Stave & Kopainsky 2015). Simulations can be used to evaluate the intended and unintended effects of value chain policies and interventions over the short-, medium-, and long run. Information about the costs and effects of value chain interventions can provide useful support in identifying strong leverage points for policy change and uptake, i.e., areas where small change can yield large improvements (Kim 1999).

For the purposes of analyzing policy interventions and setting investment priorities in value chains, SD models have a distinct advantage over qualitative methods like VCA. SD models explicitly endogenize and quantify the behavior of the chain and chain actors, providing a laboratory for empirical analysis (Rich et al. 2011). For example, in the context of dairy, SD models can endogenize producer decisions associated with investing or divesting in improved pasture based on their profitability. As a modeling tool, SD is interdisciplinary and captures the evolution and interactions between complex economic, social, and ecological systems over time. Combined with its graphical output format, this eases communication across disciplines. A particular benefit with SD modeling is that it can be conducted jointly with key stakeholders in the value chain. A participatory process called group model building (GMB) provides a methodology through which value chain actors and enablers can participate in all or some of the steps in the modeling process (Hovmand 2014; Vennix 1996). This process facilitates learning and shared understanding about the system among the participants, develops a more useful model, and enhances the commitment to selected strategies and their implementation, which leads to strengthening the sustainability of value chain interventions and policies (Lie et al. 2017). This process is briefly discussed in the next section.

3.2 Data collection and model development

Data collection and model construction were completed through a group model building process with key stakeholders in the Matiguás dairy value chain. The GMB process was implemented between March and June 2015, with a follow-up meeting in April 2016. Altogether, five group meetings were organized. Each session was carefully planned using scripts that included goals, the agenda, timings, and chosen group methods (Andersen & Richardson 1997; Luna-Reyes et al. 2006). On average, 13 participants contributed during each session. They included four small- and medium-scale farmers, three cooperative managers, one local processor, three municipal government representatives, and seven participants from research and development organizations, i.e., Heifer International, International Center for Tropical Agriculture (CIAT), Tropical Agricultural Research and Higher Education Center (CATIE) and the Nicaraguan research and development institute Nitlapan. The GMB meetings were supplemented by meetings with a reference group consisting of experts on various aspects of the dairy value chain. Additionally, key informant interviews were conducted with cooperative leadership, credit institutions, an industry actor in Managua, the Nicaraguan Chamber of the Dairy Sector (Canislac), and several informal processors and dairy sales outlets in the town of Matiguás.

The GMB stakeholders provided information about the flows, processes, and relationships between the different nodes and actors in the chain. They also provided detailed information such as the amount of milk produced in Matiguás, as well as amount produced per cow, effects of feed on milk and cattle production, delays in the system (both biophysical and those associated with decision making), and information about costs and revenues. Data from the national census (INIDE-MAGFOR 2013), such as number of cattle and amount of land used for cattle production, was also used. For additional information about participatory modeling and the GMB process of the Matiguás dairy value chain, see Lie et al. (2017).

The model was constructed using the software program iThink from isee systems.[2] The model is accessible online[3] to GMB participants, the reference group, and others interested in running scenarios using the model themselves. The time step 'weeks' was chosen for the model because milk production has large seasonal fluctuations that are best captured using weeks. The model utilizes the local currency, Nicaraguan Cordoba (NIO),[4] and the local land measure, manzana

[2] https://www.iseesystems.com/
[3] https://sims.iseesystems.com/helene-lie/dairy-value-chain-development-in-nicaragua
[4] 100 NIO = 3.4 USD (09.03.2017 XE.com)

(mz),[5] to make the data and analysis as relevant and accessible as possible to the value chain stakeholders, policy makers, and others who have an interest in better understanding the Matiguás dairy value chain.

3.3 The system dynamics model of the Matiguás dairy value chain

The top policy goals identified by the stakeholders in the first modeling session were to increase the production of milk, both in terms of quality and quantity, and to achieve higher income off the value chain actors. During the same session, a deficient feeding system was identified as the main constraint. The feed system in Matiguás consists of traditional pastures, improved pastures, cut- and-carry grasses, some crop residues, and the use of concentrates, each impacting milk productivity differently. Feed production fluctuates highly throughout the year as a result of the alternation between rainy (7 months) and dry season (5 months). This causes major fluctuations in milk production. In the past, milk production has increased mainly as a result of land expansion. Presently, pasture land expansion to increase feed production is no longer an option. Since most pastures consist of traditional species with poor nutritional quality, particularly during the dry season, possibilities are limited to significantly increase milk yields. Therefore, GMB participants concluded that the main focus of the model should be on policies and interventions that could enhance feeding systems to improve milk quantity, especially during the dry season, as a means of increasing small- and medium-scale farmer profits.

To conduct what-if-scenarios for identified policy options (more details on this in section 3.5), we constructed a quantitative SD model. The SD model of the Matiguás dairy value chain consists of four modules that each focus on a separate sub-system of the value chain: herd dynamics, milk production and sales, feed dynamics, and financial aspects. The herd module represents the development of animals from birth to mature cows. This is a crucial input for the milk module, which covers the production of milk that can be collected and processed before marketing and consumption. Feed is the key input in animal and milk production. The feed module differentiates between improved and traditional pastures and the use of concentrate. All three modules generate costs, while the herd and milk modules also produce revenues. Both aspects are summarized in the finance module, which is divided into two submodules, one that assembles costs and revenues, while the other highlights investment dynamics that transform

[5] 1 manzana = 0.7 hectares

profit information into investment decisions that feed back to other modules. Figure 1 presents a high-level map of the model and illustrates how the modules are interconnected. The lines indicate bundled flows (black) and bundled connectors (green). Bundled flows represent material flows between modules or sectors. The bundled connectors capture the high-level information connections between them. See appendix A for a stock and flow structure, and description, of each module and see Lie & Rich (2016) for a detailed description of main feedback loops of the model. All baseline data can be found in appendix B and equations in appendix C.

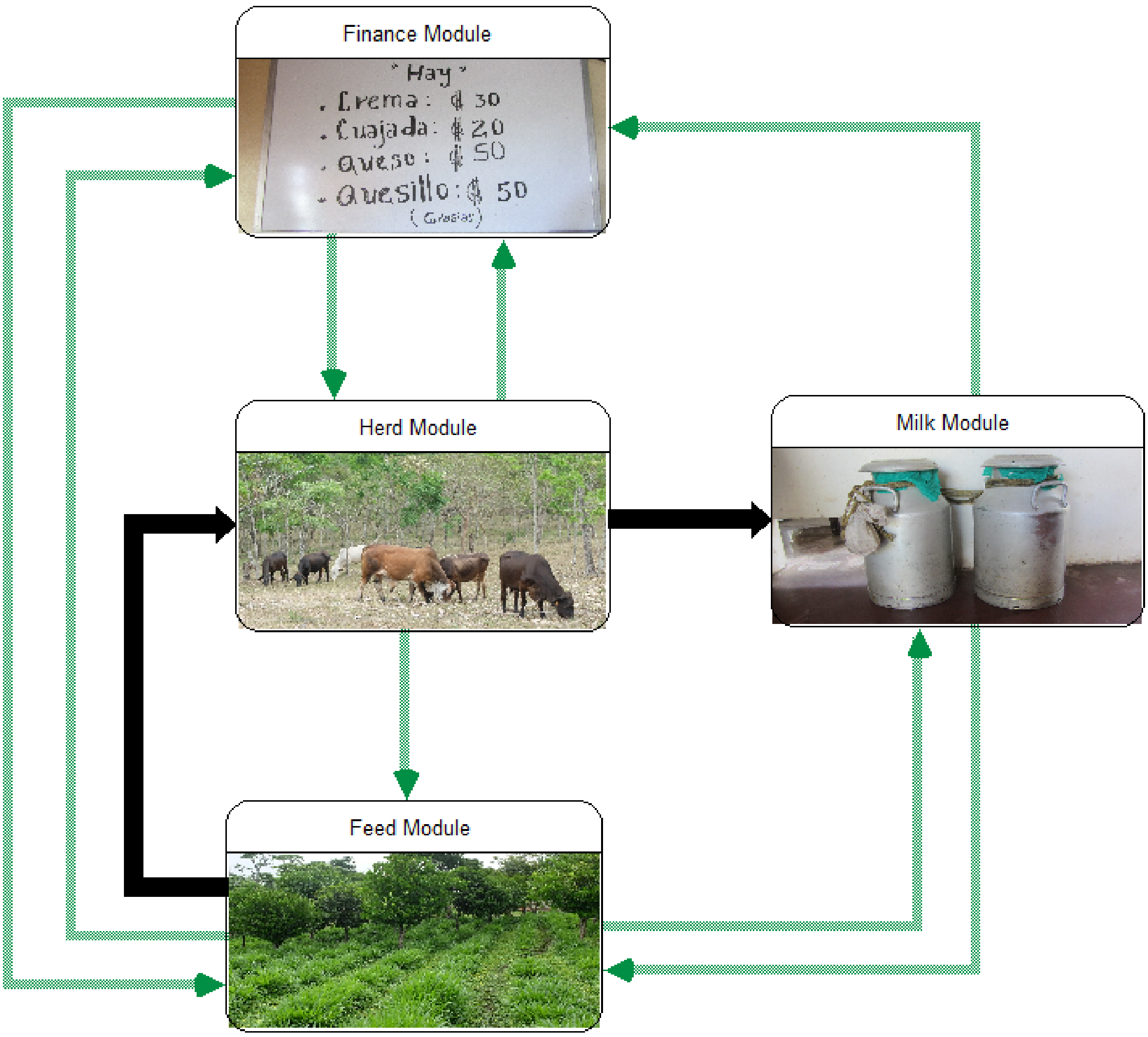

Figure 1: High-level map of the Matiguás dairy value chain model. Source: Developed by the authors

3.4 Model validation

Model validation is about building confidence in the model (Forrester & Senge 1980). The GMB process validated the structure of the SD model of the Matiguás dairy value chain in various ways. The group itself sketched the structure of the model after receiving an introduction to SD modeling, its language, and procedures. The group also chose which problem to focus on, discussed and agreed on the boundary of the model, and provided data. Behavior reproduction tests focusing on milk production were completed with the GMB group – i.e., GMB participants created a reference mode due to lack of historic time series data (Forrester & Senge 1980; Sterman 2000). The timing of the low and high seasons for milk production was also confirmed, the dry season occurring from the beginning of the year until mid-May. On average, in the model each farmer owns 23 mz, which is in accordance with the census data in the area. The GMB process was duly documented to ensure recoverability of the progression and choices made during the model building process, which strengthens its reliability.

In addition to the thorough model evaluation throughout the GMB process, parameters have been extreme condition tested to make sure the model behaves realistically. All graphical effects were also thoroughly tested for sensitivity as these are variables that drive the dynamic behavior in the model (Forrester & Senge 1980; Sterman 2000). The model has dimensional and parameter consistency without parameters that have no real world meaning. Details about equations and parameters can be found in appendices A and B.

3.5 Scenarios for policy analysis

The GMB group identified several possible policies to achieve their value chain goals. The policies were narrowed down by using the qualitative conceptual model developed during the GMB process (see Lie & Rich 2016). The selected policies to test were: (1) increasing the use of concentrates during the dry months; (2) increasing the amount of land used for improved pasture; (3) increasing the number of dairy cows; and (4) a combination of policies (1) and (2). In addition to these four policy interventions, we simulate a baseline run based on collected data to create a benchmark to compare policy interventions relative to status quo. We also conducted different types of sensitivity analysis associated with the occurrence of drought and simulated changes in prices for concentrates.

Baseline: The baseline is parametrized based on data provided during the GMB sessions. In the baseline, 20% of the cows are fed concentrate and about 42% of land is used for improved pasture, with 53% devoted to traditional pasture, and 5% to cut-and-carry grasses. The baseline is also run with a drought simulation where we simulate a drought occurring from week 104 and lasting for two years. Drought has occurred in Matiguás more frequently the past ten years, the last one from 2014 to 2016 as a result of a strong "El Niño". Under these conditions, we assumed that during the dry season (week 1-23) the productivity of traditional pasture falls by 50%. Based on research results productivity of improved pasture and cut- and-carry grasses only falls by 30% (Miles et al. 2004; Peters M et al. 2011), which is an incentive to invest in these technologies since drought is becoming more common. Many improved grass species are drought adapted.

Scenario 1: Concentrates can complement dry season grazing when the amount and quality of feed are low. They are expensive, and thus they must yield a quick positive return on investment to make it feasible for producers. They are typically only given to lactating cows to boost milk production. In Scenario 1, we considered improvements to concentrate use in two ways. First, we boosted the impact that profitability has on farmer decisions to use concentrates by modelling a 20% increase to the total effect that short-term profits have on investment decisions. In other words, for a given change in short-term profits, farmers will invest 20% more in concentrates than in the baseline. We selected the level of 20%, a fairly high percentage, because investing in concentrates only applies to some months of the year so that any potential losses can be recovered during the same season. This level could be further facilitated by policies that promote better access to short term credit (e.g. microcredit facilities). Access to concentrates in general is also a precondition for this scenario. As we do not precisely know how sensitive farmer investments in concentrates are for a given change in profitability, we conducted sensitivity analysis on the investment percentage that ranges from 5% to 25% in intervals of five percentage points (see Appendix D).

Second, we assumed that the fraction of cows consuming concentrates increased by 50% to 70%. Although the increase from 20% to 70% is arbitrary, it is not an unrealistic assumption if concentrate prices go down, interventions are put into place that promote local production, and milk prices remain more and less constant. The advantage of concentrates is that they are very easy to administer and more importantly greatly increase milk production. This scenario could be brought about by a combination of policy measures: subsidies, training on (artisanal) production of concentrates, and even certification schemes that stimulate planting or conserving leguminous trees that produce concentrate ingredients. The level of concentrates given to lactating cows is driven by the gap between the desired amount of protein per animal and the level of feed produced (measured in kg of protein[6]). Both of these shocks were assumed to take place from week 104 in the simulation. Similar to the baseline, we also ran a drought simulation, with a two-year drought commencing in year 2. In scenario 1, we also ran several simulations to analyze the effects of changing the price for concentrate.

Scenario 2: In the model, we assume that changing between traditional and improved pasture is influenced by the level of expected profit over the medium-term. If farmers experience higher profits than expected over the medium run, we assume that they will make investments to transform their land use from traditional into improved pasture. The total amount of land is constant since land availability is limited, and hence the focus is on intensification. In scenario 2, we assume that higher medium term expected profits will lead to 10% more investment in improved pasture relative to the baseline. We chose a lower investment percentage in this scenario since it applies to the entire year and most likely requires several years to be successful. From a policy standpoint, this would require access to longer term and larger amounts of credit, and an enhanced rural financial market to facilitate. Access to seeds, equipment, and information about pasture management are preconditions for this scenario. As with scenario 1, since we do not precisely know how sensitive farmer investments in pastures are for a given change in profitability, we conducted sensitivity analysis on the investment percentage that ranges from 5% to 25% in intervals of five percentage points (see Appendix D).

As before, drought simulations similar to the baseline were also implemented here. In this scenario, an additional source of sensitivity analysis was to consider the role that farmer knowledge plays in improved pasture management. Here, we considered the impact of improved learning (through participatory training) on pasture management, productivity and

[6] Protein is used as the metric of measurement for feed since protein is the most limiting factor for milk production. Many types or large quantities of dry matter of feed could be available, but if their quality is low (in protein terms) it will not lead to higher levels of milk production. This is also the reason for complementing grazing with concentrates, which has a high level of protein (see more information in Appendix A).

farmer profitability. We ran simulations that introduce training to improve farmer pasture management skills starting in week 104. These simulations last for three years and eventually reach 50% of farmers over time.

Scenario 3: The decision to buy or sell dairy cows depends on long-term profitability. In the model, we assume that farmers will invest in dairy cows if expected profits over a three year time horizon are greater than expected. Similarly, dairy cows will be sold if farmers experience sustained long-term losses or if there is not enough feed for all animals. In scenario 3, we assume that changes in long-term profits will change investments in dairy cows by 10% more than the baseline from week 104. We use 10% in this scenario as well since investing in dairy cows requires a larger investment amount as enlarging the herd is a major decision for a smallholder farmer. Similar to scenario 2, access to formal credit and the development of strong rural financial markets are important policy levels to facilitate such a scenario. As with scenarios 1 and 2, this scenario also includes a drought simulation. As with scenario 1, since we do not precisely know how sensitive farmer investments in dairy cows are for a given change in profitability, we conducted sensitivity analysis on the investment percentage that ranges from 5% to 25% in intervals of five percentage points (see Appendix D).

Scenario 4: Scenario 4 combines scenario 1 and scenario 2, since investments in improved pasture to increase feed quality in the medium and long term are often combined with using concentrates in the dry season for a short term feed quality increase.

The model online includes additional versions of the scenarios. The GMB sessions were primarily held in 2015, so that the model starts in January 2015 and runs for ten years (520 weeks) until 2025. Each scenario was evaluated over different lengths of run (short, medium and long term). Any policy introduced in a given scenario starts in 2017, which is year two (week 104) in the model. We define short-term as the two years following the implemented policy (until week 208). We define medium-term to be the third to fifth year after intervention (until week 364), while long-term is defined as the sixth to eighth years after a policy is implemented (until week 520).

The policy analysis primarily focuses on producer milk inventory and small- and medium scale farmer profitability (on a weekly basis and cumulatively in the short (4-year)-, medium (7-year)-, and long (10-year)- term). Where relevant, we also report the total cattle population and land distribution between improved and traditional pastures (feed availability) to understand the drivers of milk production and profit. In the following results section, a summary of cumulative farmer profit and milk production over the short-, medium-, and long run is presented. This is followed by presenting dynamic weekly results, which provide details on how the numerous feedbacks between and within the modules leads to intended and unintended consequences due to changes in policies.

4. Results

4.1 Cumulative results

Table 1 summarizes the results for accumulated discounted farmer profits over the short-, medium-, and long- term using an annual discount rate of 5% that is adjusted weekly. Table 1 also reports changes in cumulative profit in policy scenarios relative to the baseline. Similarly, table 2 presents values and percentage change figures (relative to the baseline) of cumulative milk production over the different time scales.

Increasing the use of concentrates (scenario 1), increases milk yield by +6% to +11% over the simulation time horizon (see table 2), although generates losses (-3%) relative to the baseline. This suggests that the current price of concentrate is too high to make it viable for producers to invest in concentrates. However, a 20% discount in the concentrate price (see Scenario 2 + 20% discount in the concentrate price) does increase profit by +4% to +9% and milk yield by +7% to +12% relative to the baseline. We have conducted a sensitivity analysis of the concentrate price (see Appendix E), which reveals that a 20% decrease is required for concentrate use to be profitable when milk production is lowest. Buying in bulk, e.g., through cooperatives, would reduce prices but likely not up to 20%. Another option would be local production of concentrates, using locally produced ingredients, for instance based on high protein legumes produced on-farm and agricultural byproducts (brans). Initial investments (equipment) could be supported by the local government or development organizations.

Investments in improving pasture quality (scenario 2) result in an increase in milk yield by +1% (short term) to +5% (long term), but similar to scenario 1, they are not profitable, due to high initial investment costs, in the short (-3%), medium (-2%), and long run (-1%) relative to the baseline. Other investments along with pasture improvement are thus needed to increase farmer profitability. Indeed, by investing in farmer training (scenario 2 + training) in pasture management, long-term milk yields and profits increase by 10% and 7%, respectively. However, due to high investment costs, scenario 2 + training is not profitable in the short term (3% fall in profits) and only breaks even in the medium term. This is due to high investment costs in improved pasture, and that pasture is a long-term investment. Training in pasture management will be paid externally and not impact farmer profitability beyond increasing their milk yield by improving farmer capacity to maximize the use of improved pastures. Training can be provided in different ways. One way is through the government and mainly paid through soft loans from the World Bank, Inter-American Development Bank (IADB), the International Fund for Agricultural Development (IFAD) (already on-going), and development organizations such as Heifer International. They could also be funded directly by cooperatives, either through members or in combination with development organizations.

Investing in additional dairy cows is not profitable (-1%) in the short term and only breaks even (0%) in the medium- and long-term and does not lead to any change in milk production, and hence should be discouraged by policy-makers until higher quality and quantity feed is available (see scenario 3 in table 1 and 2).

On the other hand, scenario 4 (combining scenarios 1 and 2 – i.e., using concentrates and improving pasture simultaneously) increases milk yields by +7 to +16%, but has negative consequences on profits (-5% in the short term to -4% in the long term), again due to high investment costs. However, similar to scenario 2, applying scenario 4 along with training producers to manage improved pastures generates positive results in the long term (+5%) relative to the baseline. However, the short- and medium-term profit figures are still negative (-5% and -2%, respectively) relative to the baseline.

These results suggest that policy-makers should acknowledge that intensifying feeding systems to improve milk yields is only profitable in the long term and requires support in the interim to induce and sustain these investments. This means that during the first phase (initial 5 years) of investment producers may need to be supported by government, development organizations, and/or private sector. Alternatively, policy makers could consider strategies that reduce input costs to obtain positive returns in the short-term. Similarly, an aggressive policy strategy (i.e., simultaneously applying all scenarios – improved pasture + concentrates + training + lower concentrate prices) generates strong positive profits in the short and long term (from +1% in the short term to + 16% in the long term) relative to the baseline. In general, these results suggest that there is no single intervention that can improve producer incomes, particularly in the short-term. Instead, a suite of policies will be needed to consider the dynamic impacts that different options may have on farmers.

It is important to note that while we have focused our attention on the gains associated with producers in our scenarios, we have not considered the costs to external parties that might facilitate their implementation (government, NGO, and/or private sector). Indeed, while the aggressive policy strategy noted above has the most positive effects on producer profitability, it may come at a high cost to achieve. Data limitations prevented us from computing the returns on the investment scenarios given here, as information on the costs of achieving these scenarios was unavailable. Having said that, our model still provides useful information and a platform for policy dialogue for decision makers to understand the potential impacts that policies could have on the value chain, and to provide guidance on the need to shape policies – and their costs – to achieve desired outcomes.

Table 1: Cumulative farmer profits from the simulation analysis

	Short term		Medium term		Long term	
	NIO (*1000)	Change (%)[a]	NIO (*1000)	Change (%)	NIO (*1000)	Change (%)
Baseline	146	-	228	-	301	-
Scenario 1	142	-3	222	-3	292	-3
Scenario 1 + 20% decrease in concentrates price	152	+4	245	+7	328	+9
Scenario 2	142	-3	223	-2	303	-1
Scenario 2 + training	142	-3	229	0	324	+7
Scenario 3	145	-1	227	0	300	0
Scenario 4	138	-5	216	-5	288	-4
Scenario 4 + training	139	-5	223	-2	315	+5
Scenario 4 + training and 20% decrease in concentrate prices	148	+1	244	+7	348	+16

a Percentage change relative to baseline

Source: Simulation results

Table 2: Cumulative milk production from the simulation analysis

	Short term		Medium term		Long term	
	Million kg	Change (%)	Million Kg	Change (%)	Million kg	Change (%)
Baseline	93	-	160	-	230	-
Scenario 1	98	+6	176	+9	255	+11
Scenario 1 + 20% decrease in concentrates price	99	+7	177	+10	257	+12
Scenario 2	93	+1	166	+3	243	+5
Scenario 2 + training	93	+1	168	+5	254	+10
Scenario 3	93	0	161	0	230	0
Scenario 4	99	+7	181	+13	268	+16
Scenario 4 + training	99	+7	182	+14	277	+20
Scenario 4 + training and 20% decrease in concentrate prices	99	+7	183	+14	279	+21

Source: Simulation results

Table 3 and 4 summarize scenarios in which droughts take place. Scenarios 1, 2, and 4 all result in higher cumulative milk production in the short-, medium-, and long-term relative to the baseline, but only lead to profitable milk production in the long run, except for scenario 1, relative to baseline + drought. An increase in concentrate use is not profitable without a price reduction. Hence, to support farmers to deal with drought, policy-makers should support farmers with investment in improved pastures combined with training in pasture management. When drought occurs, farmers start selling cows to deal with the lower feed availability and limit losses (see scenario 2 and 4 in table 4). In this case, drought lasts for two years, which in the medium run results in farmers starting to sell fewer cows to recover their herd to the size before the drought. This leads to an increase in milk production, but profitability lags behind.

Policy makers could advise farmers to use a higher amount of concentrates during the dry season through policies that improve farmer access to credit. This would boost the milk production during the dry season and enable farmers to supply a larger amount of milk to cooperatives, which strengthens their position towards the dairy industry. Policy makers could on the other hand subsidize concentrates when droughts occur as a temporary policy that can be put in place quickly. This would result in higher milk yields, and secure farmer ability to supply cooperatives. On the other hand, such subsidies would be quite expensive, and suggest a need to think of institutional mechanisms that could deliver similar outcomes at lower cost.

Table 3: Cumulative milk production in drought scenarios

	Short term		Medium term		Long term	
	Million kg	Change (%)	Millio n kg	Change (%)	Millio n kg	Change (%)
Baseline + drought	86	-	144	-	213	-
Scenario 1 + drought	93	+7	157	+9	234	+10
Scenario 2 + drought	87	+1	151	+5	228	+7
Scenario 2 + drought + training	87	+1	152	+5	241	**+13**
Scenario 4 + drought + training	93	**+8**	163	**+14**	262	**+23**

Source: Model simulations

Table 4: Cumulative farmer profit in drought scenarios

	Short term		Medium term		Long term	
	NIO (*1000)	Change (%)	NIO (*1000)	Change (%)	NIO (*1000)	Change (%)
Baseline + drought	170	-	229	-	290	-
Scenario 1 + drought	168	-2	224	-2	283	-3
Scenario 2 + drought	169	-1	220	-4	295	**+2**
Scenario 2 + drought + training	169	**-1**	221	-3	303	**+5**
Scenario 4 + drought + training	166	**-2**	216	-5	395	+2

Source: Model simulations

4.2 Dynamic results

4.2.1 Baseline results

Baseline results from the model show that small- and medium-scale dairy farmers in Matiguás experience expected large seasonal swings in milk production. The GMB group stated that about 100,000 kg of milk is produced every day in Matiguás. As this model only focused on small- and medium-scale producers in Matiguás, the group estimated the average weekly amount of milk production to be about 450,000 kg of milk with seasonal swings. The model simulation results reveal levels of milk inventories of 443,000 kg of milk per week on average over ten years. The group also estimated that there is about a 50% difference in milk production between the dry and wet season, but that a larger or smaller difference could also occur depending on the feeding system. Model results under baseline assumptions show milk production ranges from approximately 325,000 kg in the dry season to 580,000 kg of milk per week in the best peak season for milk production (see figure 2 below and figure F.1 in Appendix F).

The baseline scenario includes a fixed use of concentrates to 20% of the cows in the dry season, which is based on estimates from the GMB participants. Without the use of concentrates, the difference in milk production between the wet and dry season would be even larger. Milk production falls slightly during the first three years, which is in accordance with the reference mode with no interventions made by the GMB participants and due to low feed production and limited land availability. The total cattle population shows a slight increase of just under 4,000 animals over 10 years.

During the dry season, milk production is not profitable. The profitable rainy season leads to some investments in improved pasture, resulting after six years into equal areas of improved and traditional pasture (see figure F.2 in Appendix F). In the baseline, farmers earn on average about 2,900 NIO (97 USD) per month (see figure 3 below). The limited profit during the peak milk production season influences the resilience of farmers in case of decreasing demand or milk prices.

4.2.2 Scenario 1: Increasing the use of concentrates during the dry season

Concentrates are an effective, but costly, way to increase milk productivity and therefore are only used when feed is scarce, farmers have sufficient cash, and the return on investment is positive. In this scenario, concentrates are only fed to dairy cows during dry months when there is not enough feed available. In scenario 1, we assume that 70% of cows receive concentrates compared to the baseline of 20% based on the current situation in Matiguás reported by the GMB group. If farmers are not sufficiently sensitized about the benefits of concentrates, or lack access to them, a smaller percentage of the cows would receive concentrates. Additional cows receiving concentrates and greater concentrate use substantially increase milk production in Matiguás (see milk production under scenario 1 in Figure 2) and the gap between milk production in the dry and wet season is reduced by about 50%. The ability to provide a constant or less fluctuating supply to the dairy industry makes small- and medium-scale farmers potentially more competitive. Policy makers can facilitate increased use of concentrates by sensitizing farmers about their benefits through extension officers and cooperatives, but reducing the price of concentrates would have the greatest effect in increasing their adoption.

When drought occurs, dry season milk production is above its baseline value, with feeding concentrates making up for the feed deficit. During the rainy season, milk production is severely reduced (see milk production in scenario 1 with drought in figure 2). It takes about six years for the amount of milk produced after the drought to fully recover. This illustrates the risks farmers face when dealing with erratic weather. Drought results in an increase in profit in the short run, a considerable reduction in profits in the medium run, and in the long run the scenario reverts back to the pre-drought situation since the drought lasts only two years and farmers make decisions according to feed availability and profit (see figure 3). Drought results in farmers selling dairy cows in the short run to cope with the drought, which leads to an initial burst of short-term profit but a subsequent, substantial reduction in milk production and income in the medium term. These dynamic effects highlight the power that SD models convey in revealing how value chains adjust to external shocks that qualitative methods do not provide. On the other hand, investment in concentrates does not impact the number of dairy cows (see scenario 1 in figure 4) since concentrate is used over the short term and has little effect on long term behaviors such as investing in dairy cows.

The use of concentrates is in general not profitable. In scenario 1, the gains from increased milk production are offset by high concentrate costs at the current price. However, sensitivity analysis reveals that if the price for concentrates falls by 20%, farmers can break even. Finding ways to access cheaper concentrates could improve smallholder competitiveness in the Matiguás dairy value chain. As mentioned above, bulk buying and local production are ways to accomplish this.

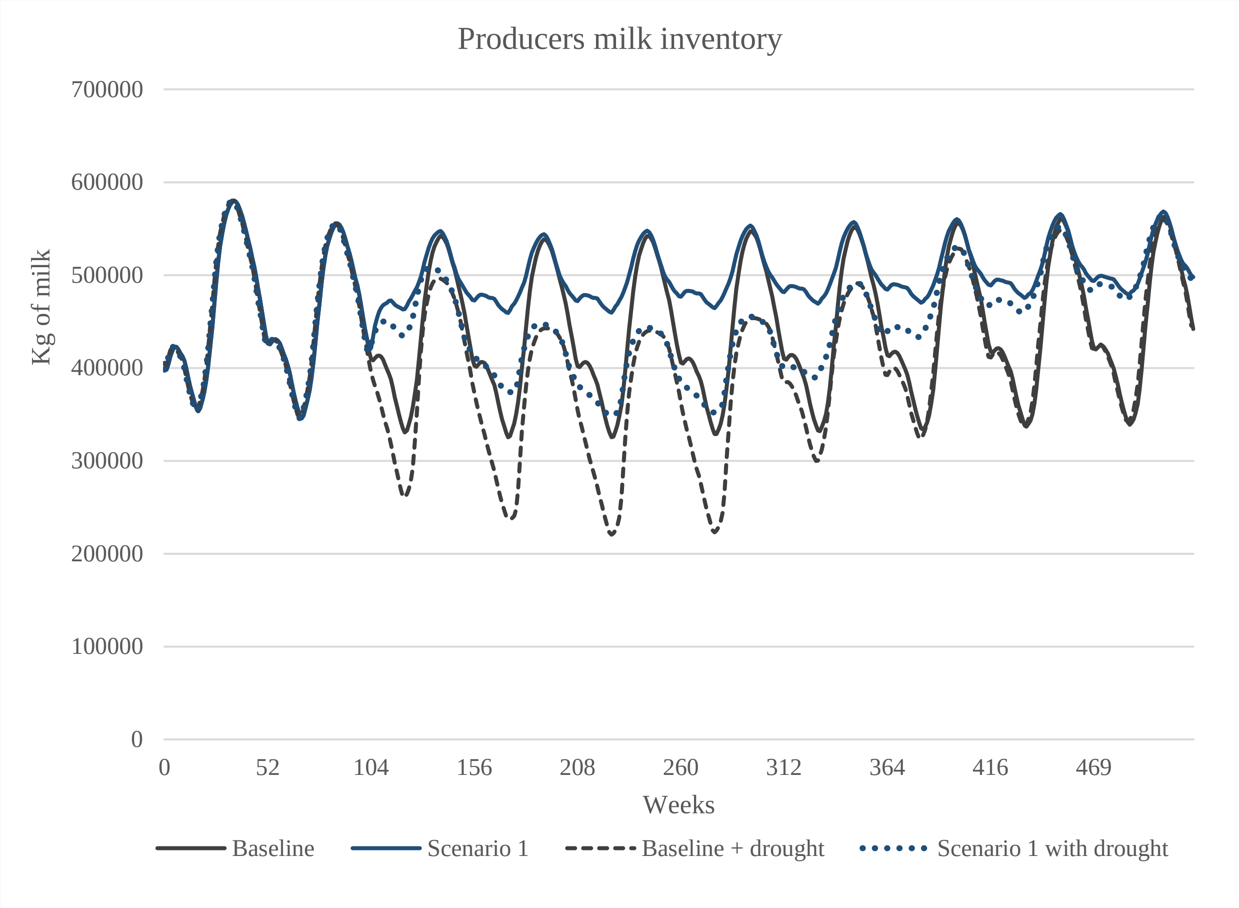

Figure 2: Producer milk inventory in the baseline scenario and scenario 1. Source: Model simulations

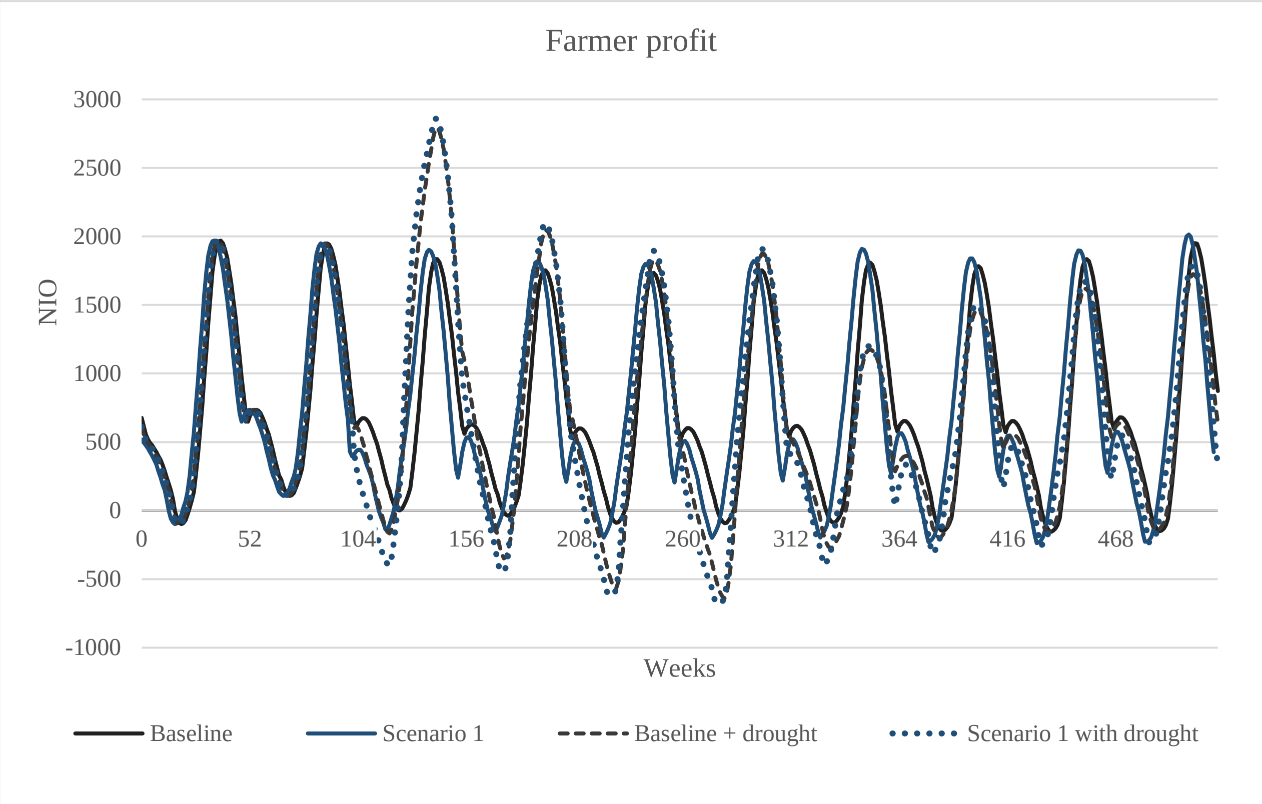

Figure 3: Farmer profit in the baseline and scenario 1. Source: Model simulations

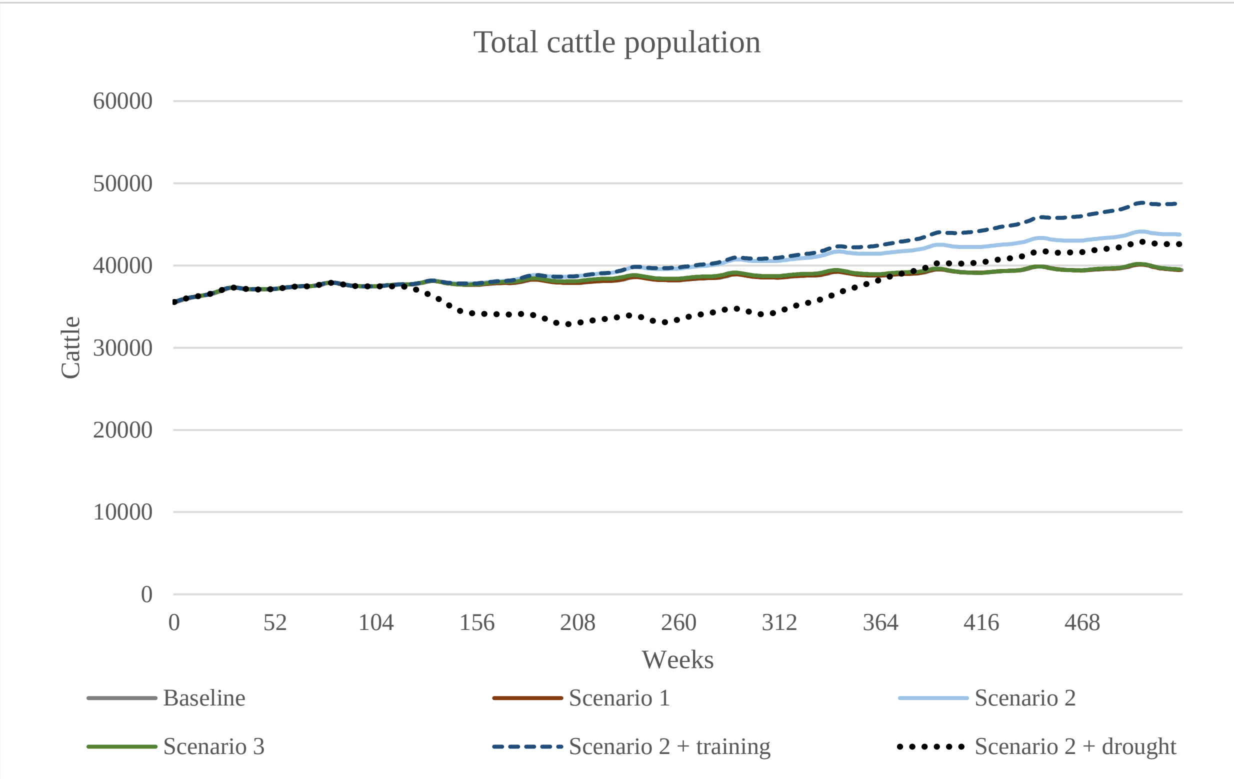

Figure 4: Total cattle population in different scenarios. Source: Model simulations

4.2.3 Scenario 2: Investments in improved pasture

Improved pastures increase feed volumes and quality. Many improved grass species, like Brachiaras, are drought adapted. However, they come with additional costs (seed, labor) and farmers need to assess the tradeoffs with the extra income from the increase in milk production. In scenario 2, the amount of land allocated to improved pastures steadily increases in accordance with the boost in investment (see figure 5). The sensitivity analysis in appendix D highlights that different assumptions regarding producer investment behavior in pastures given a change in profitability imply significant differences in the speed and percentage of land allocated to improved pastures over the ten-year simulation period. Increasing the responsiveness of farmer investment to profitability (through improved rural financial markets or enabling environment) could speed up this process considerably. The implications of this scenario on milk production are substantial. Improved pastures increase milk production in the peak season by 14% in the long term from 540,000 in the short term to 615,000 kg/week in the long term (see figure 6), and by 19% between the dry season in the short and long term.

When pasture investments are combined with farmer training and extension, we observe much higher milk yields over time (particularly in the long run) due to increased pasture productivity, more feed, and higher milk yields per cow (see scenario 2 + training in figure 6). In this sub-scenario, we initiate training at the same time as introducing improved pastures. Policy makers can support the adoption of improved pastures by investing in participatory training, like farmer field schools, establishing model farms, and training technicians and extension agents. In Matiguás, such a strategy has led to the training of 1,000 farmers, of whom 400 have established 5,800 mz of improved pastures. Improving availability and access to medium and long term credit would greatly increase the number of farmers able to invest in improved pastures, but access is limited. Cooperative members have usually only access to short-term credits.

Investing in improved pasture slightly reduces farmer profits in the short run during the peak season due to initial investment costs, and cumulative profit shows similar trends in table 2. Costs of traditional pasture are 32% lower than that of improved pasture. In the long run, profits return to scenario 1 values (see figure 7). As in scenario 1, scenario 2 milk production gains and sales are offset by higher investment costs in improved pasture. Improved pasture is only beneficial if combined with proper training of farmers, with milk production under this scenario reaching nearly 700,000 kg/milk per week. It also raises dry season milk production by 120,000 kg/milk per week, a 35% increase relative to the baseline. It also leads to an average monthly profit of nearly 3,200 NIO. Investment in improved pasture combined with training is a long term intervention, leading in the short to medium run to reduced profitability, but with a gradual profit increase in the long run (see scenario 2 + training in figure 7, and cumulative profit numbers in table 2). The decline in profit in years 7-8 (approximately week 330-390) is due to lower sales of dairy cows as improved pasture productivity encourages producers to increase their cattle herd. This in turn results in a gradual increase in milk production and profitability in the subsequent periods.

In the case of drought, milk production decreases substantially during the two drought years and then gradually increases to reach the production levels associated with scenario 2. As before, this decline is partly due to the sale of dairy cows to cope with drought and reduced milk productivity (see scenario 2 + drought in figure 6). Improved pasture is more drought resistant and produces more feed, resulting in higher production and a faster recovery to pre-drought scenario levels (see figure 6). During drought periods (see scenario 2 + drought in figure 7), profits increase substantially in the short run because farmers sell dairy cows. Profits decline in the medium run and gradually approach pre-drought levels in the long run as the effect of drought dissipates. Investing in improved pasture is thus a good policy to increase farmer resilience to drought. Trained farmers are also better prepared to handle drought, which lowers the impact that drought has on milk production and profitability.

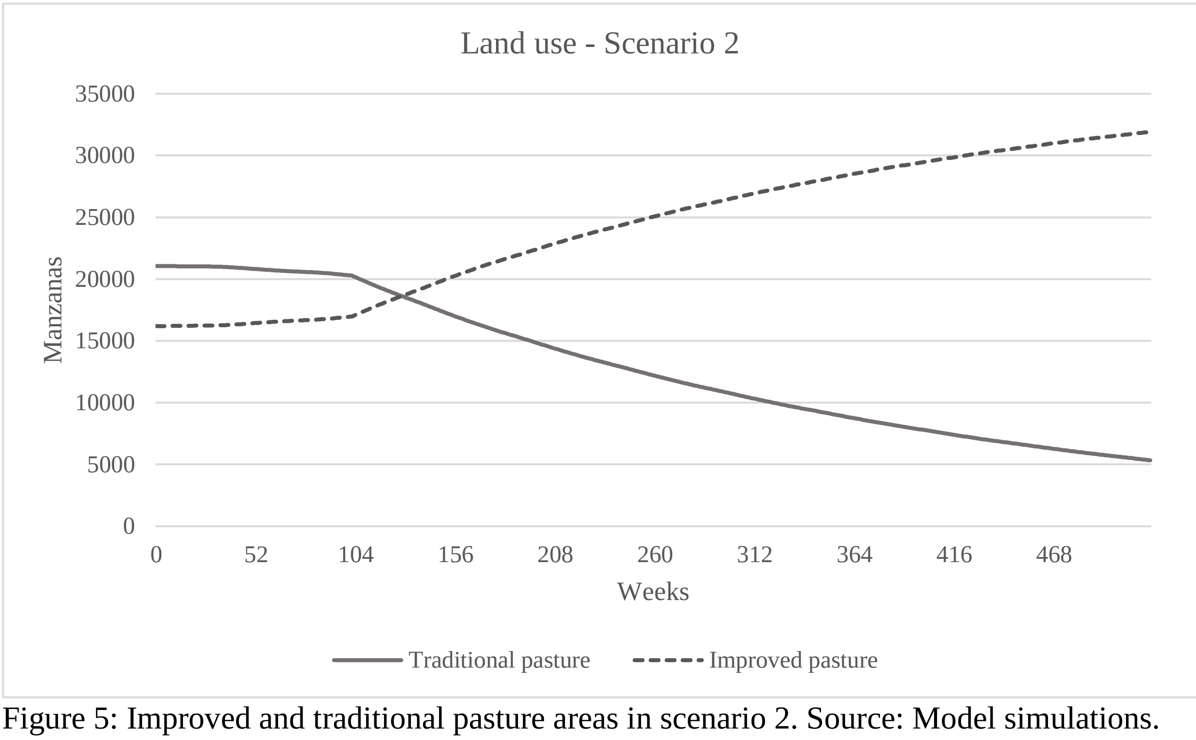

Figure 5: Improved and traditional pasture areas in scenario 2. Source: Model simulations.

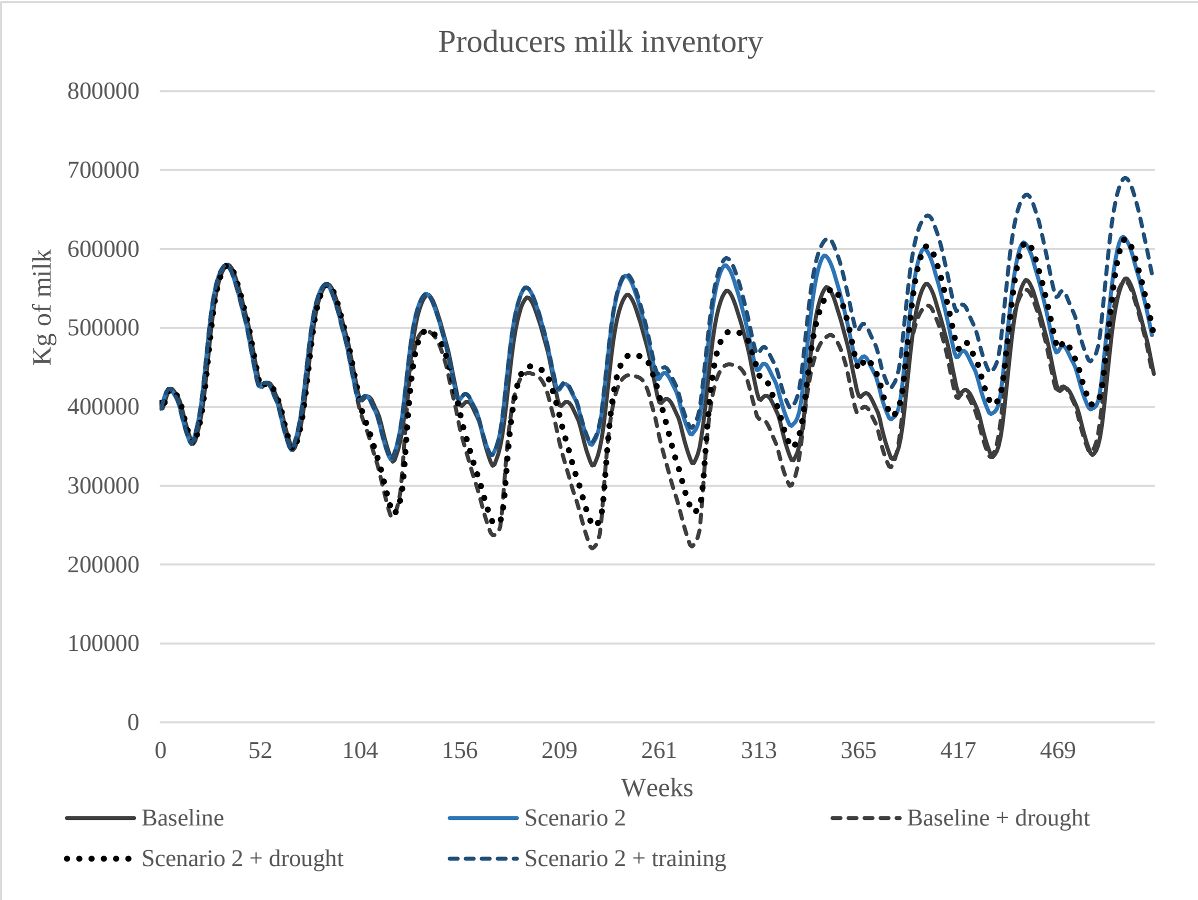

Figure 6: Producer milk inventory in baseline and different versions of scenario 2. Source: Model simulations

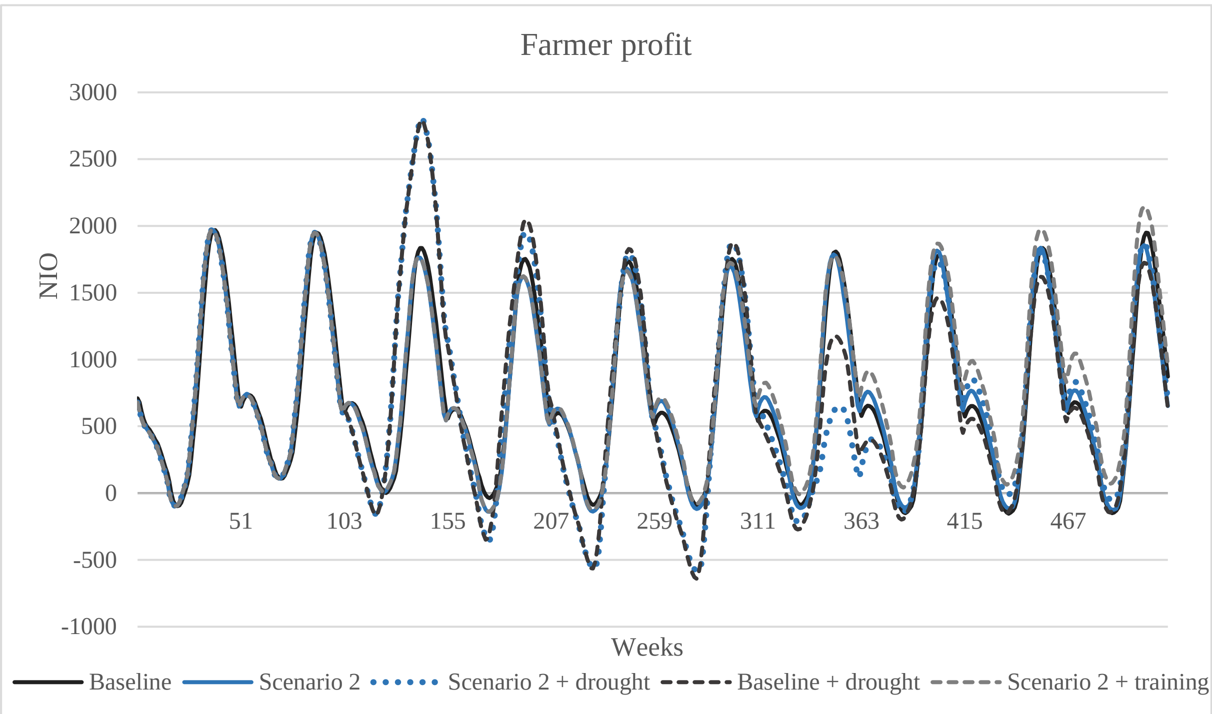

Figure 7: Farmer profit in baseline and different versions of scenario 2. Source: Model simulations

4.2.4 Scenario 3: Investments in increasing the number of dairy cows

An important goal of increasing the dairy herd is to increase milk production and incomes, for which adequate feed availability is key. As seen from model simulations, investing in dairy cows in Matiguás does not appreciably impact milk production (as seen in figure F.1 in Appendix F) and farmer profits only vary due to differences in the purchasing and selling of dairy cows (as seen in figure F.3 in Appendix F). Feed availability is the main driving force for sales and purchases of cattle. In Matiguás, year-round feed availability does not allow for an increase of the cattle herd: additional dairy cows bought during the rainy season are sold again during the subsequent dry season (see figure 4 above). However, if the farmers experience an excess in feed availability and higher than expected profitability in the long run, they will invest in dairy cows, as shown in the different versions of scenario 2 in figure 4 above. Strategies aimed at increasing feed availability, such as improved pasture, therefore make more sense than investing in additional dairy cows. Another option would be to invest in improved breeds that produce more milk (beyond the scope of this model, but an area for future research).

4.2.5 Scenario 4: Combination of scenarios 1 and 2

Different policies can target different aspects of one problem. An example of this is promoting improved pasture in combination with the use of concentrates. This scenario reports results of the model based on combining scenario 1 (increasing the use of concentrates) and scenario 2 (investments in improved pasture) and results in a substantial increase in milk production. Most importantly, it also leads to a substantial increase in milk production during the dry season that in the long run exceeds the peak season production in the baseline (see scenario 4 + training). Training in pasture management further boosts milk production (e.g., see scenario 4 in figure 8). When scenario 4 is combined with drought milk production drops during the dry season and increases substantially during the rainy season, recovering quickly and reaching a higher level than without drought. The balance between feed demand and feed availability is reached sooner due to the previous drop in number of dairy cows.

In scenario 4, farmer profits fall in the medium run due to investments made in improved pasture, but increase in the long run. We also see a drastic drop in profit when feed availability allows for investing in dairy cows, which leads to an increase in profit relative to the baseline (see figure 9). Training also provides substantially higher profits in the long run.

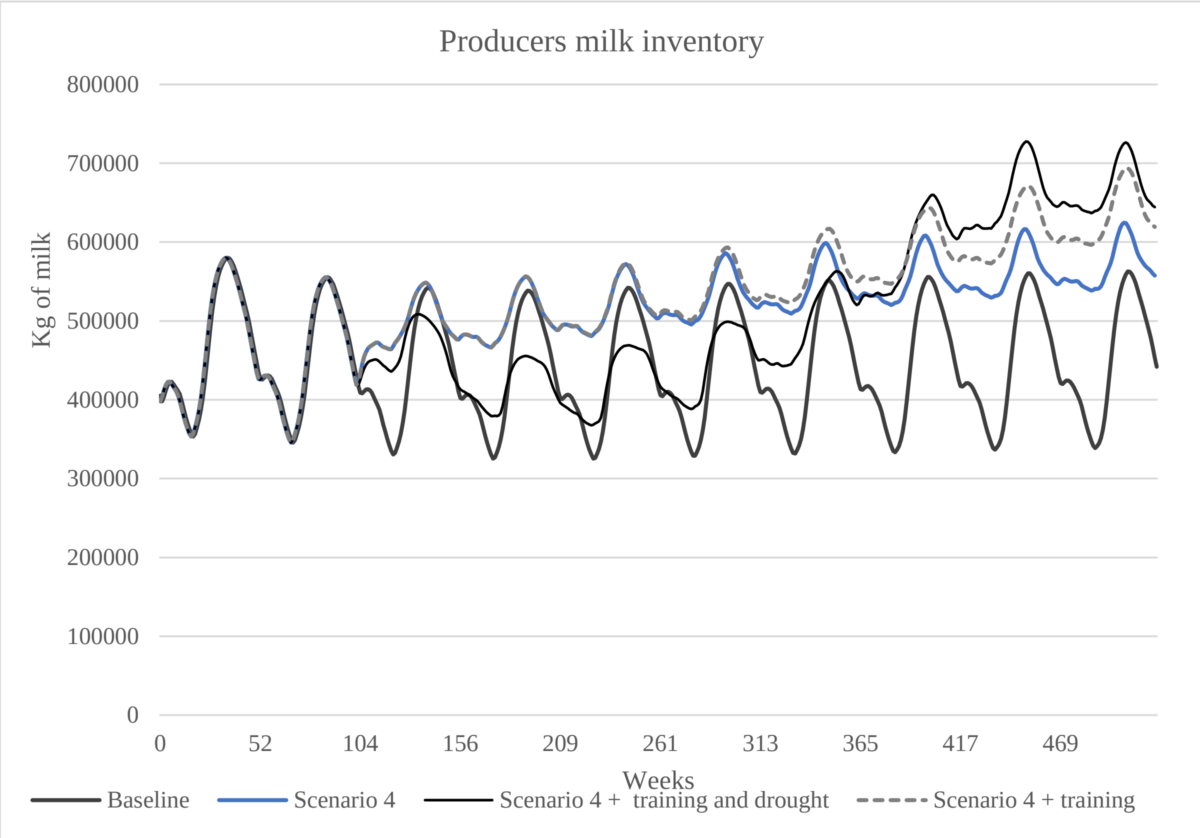

Figure 4: Milk inventory when investing in improved pasture and use of concentrates. Source: Model simulations

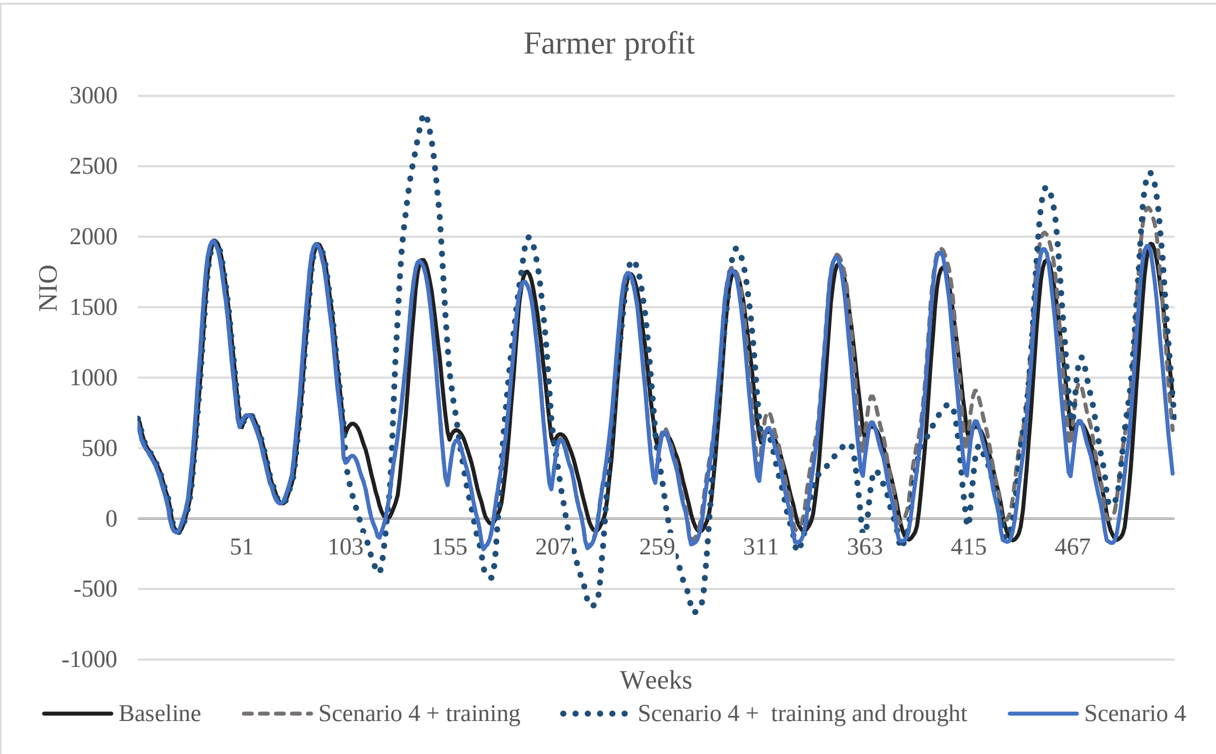

Figure 5: Profit changes for different simulations related to scenario four. Source: Model simulations

5. Discussion

Several policies and intervention options exist to improve small- and medium-scale farmer participation in the Matiguás dairy value chain. The increasingly competitive landscape of the dairy industry in Nicaragua requires that producers stabilize their milk supplies to the dairy industry and as such strengthen their competitiveness to enter and continue their participation in value chains such as in Matiguás. The analysis shows that a combination of increasing the use of concentrates during the dry season with longer term investments in improved pasture increases milk production, especially during the dry months, and increases farmer profitability. Reducing the price of concentrates would further have positive effects on farmer profits and might be possible through bulk buying or local production. National polices could be put in place to subsidize concentrates when drought occurs as a temporary policy that can be put in place quickly. Alternatives to increasing feed quality (or protein supply) are protein banks with forage legumes and leguminous trees. Apart from producing animal feed, such technologies have also a positive impact on other farming system components. Forage trees, for instance as part of silvopastoral systems, accumulate carbon, and improve soil fertility and water retention. Herbaceous legumes can be intercropped with cereals (maize), producing dry season feed (in combination with maize residues) and improving soil characteristics. Although these interventions require (some) extra labor and seed (which can be produced on-farm), monetary investments are lower than when using concentrates.

Training on pasture management is crucial in order for farmers to benefit from the higher productivity potential and to achieve high returns on investment. Experiences in the Matiguás area with participatory capacity development methodologies (i.e., Farmer Field Schools including model farms, in collaboration with farmer cooperatives) have generated strong impact, but are associated with high costs for policy makers. To be a member of a cooperative comes with access to credit, inputs, equipment, information, and technical advice. There is, however, a difference between cooperatives based on their size and professionalism. Policy makers should support cooperatives to professionalize their services. This could open up for including additional members, offering better services, as well as increase their bargaining power with the dairy industry actors to which they supply milk. Improving producer access to longer term and larger amounts of credit, and enhancing rural financial markets in Matiguás would also facilitate investment in improved pastures, since cooperatives today can only offer short-term and small amounts of credit.

In agricultural development, there has been a strong focus on technical interventions that increase productivity. Lately, strengthening market links and inclusiveness (poor farmers, women, and youth) have become more important (Devaux et al. 2016). The Matiguás SD model focuses primarily on technical interventions, but clearly illustrates the links between the different nodes in the value chain, its dynamic nature, and how different parts of the system are connected. These interrelations can, however, be difficult to realize and understand, especially for those from or working within specific disciplines or organizations intervening in only one or few value chain components. For example, investments in better pasture and increased use of concentrates to improve productivity need to be combined with establishing or strengthening market linkages. Development projects should address the chain-wide technological, economic, institutional, and social challenges to successfully promote long-lasting inclusive value chain development. To achieve this combination of policies and interventions, strong collaboration is required between stakeholders actively involved in the chain such as farmers themselves, cooperative leadership, input providers, milk buyers, etc., as well as the enabling environment such as national and local government and service providers. Additionally, the findings from this study repeatedly underline the importance of a long term perspective as it takes time to implement and see the results of interventions. A focus on the short-term may ignore important dynamic effects within the value chain that could influence the sustainability of policies over time.

SD approaches can therefore be an important decision support tool, helping decision makers and stakeholders understand and prioritize investment options. It is, however, important to remember that an SD model does not deliver predictions, but provides a deeper understanding of the behavior of complex and dynamic systems, such as value chains. Participatory processes are an important part of building this understanding, as well as providing a platform for needed collaboration across the chain. Lie et al. (2017) highlighted some of the important team-building impacts of the GMB process to develop the SD model, which in itself will have a positive influence over and beyond the modeling process.

As noted earlier, an important limitation with our analysis is the lack of information associated with the costs needed to implement the different chosen scenarios. Some of the policies conceived could be quite costly, particularly those associated with training or mechanisms that reduce the price of concentrates. While our analysis highlights value chain impacts associated with intervention options, the costs incurred by government or investors to achieve these and to compute their cost-effectiveness are unknown. At the same time, our model provides a first step in promoting a process of policy dialogue, highlighting areas where the dairy value chain can be improved and providing a platform that policy makers can use to design appropriate, cost-effective policies that can generate these effects.

Numerous additional scenarios can be simulated with the current SD model, but due to limited space the focus was on the policies identified by the GMB stakeholders themselves. In addition, different versions of scenarios 1-4 could be simulated by, for example, changing the timing and length of drought, by changing the sensitivity of investment to expected farmer profit, by testing additional price differences for milk and concentrate, and making additional changes to demand. For example, in the GMB stakeholder group, some stakeholders were interested in changing the amount of land used for the different types of feed combined with different herd numbers. Another scenario to test in the future is to consider increasing the proportion of milk going to the formal sector, implying increasing the number of cooperative members. This is important when promoting inclusive value chain development. Other interventions such as introducing improved breeds with higher milk production, or additional coordination interventions would be possible with some additional structure and the collection of new data. Nevertheless, this model provides a good starting point for continued development and assessment of various value chain interventions in Matiguás.

Some challenges with SD modeling include the need for expert modelers and software, although the latter can be mitigated somewhat by the use of newly developed, free web-based packages (e.g. InsightMaker). Using a participatory process can be time consuming, but provides additional positive outcomes such as team learning, commitment to chosen strategies, and more sustainable value chain interventions (Lie et al. 2017). Working with systemic constraints in value chains is challenging, as exemplified throughout this paper, which can justify a time- and resource-consuming SD approach.

6. Conclusion

The development and adoption of new technologies and improved practices by smallholder farmers can be a good strategy, but also a risky one. It is therefore important to carefully assess the costs and benefits of different value chain policies and interventions, and prioritize them based on their predicted *ex-ante* effects on smallholder farmers. In the Matiguás dairy value chain, investments in improved pastures combined with training in pasture management yield the highest returns in the long run. In the short run, investing in increasing the use of concentrates raise milk production substantially, but their profitability depends on finding ways to reduce the price of concentrates. The mostly qualitative value chain analysis framework from previous analyses does not allow for this type of assessment. It is also important to consider short-, medium-, and long term effects and tradeoffs between different strategies. SD modeling enables this type of analysis and communication in a value chain setting, thus providing a deeper understanding of the complex and dynamic nature of agricultural value chains and the interactions between markets, institutional coordination and governance, biophysical phenomena, and income. Another strength is the possibility of constructing and testing SD models through a participatory process, improving stakeholder learning, strengthening commitment to chosen strategies, and increasing the sustainability of interventions. SD models provide a complementary toolkit to existing value chain methods to improve engagement with inclusive value chain development processes and to target scarce donor resources more effectively.

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8. Appendices

A. Detailed modules descriptions
B. Baseline date
C. Model equations
D. Sensitivity analysis investment percentage in scenarios 1-3
E. Sensitivity analysis of price for concentrate
F. Additional model graphs

Appendix A: Detailed modules descriptions

Herd module

The herd dynamics module, illustrated in Figure A.1, consists of four stocks that represent the different stages of maturing calves to becoming dairy cows or bulls. The model starts out with 10000 *calves*[7], 5000 *heifers*, 20000 *dairy cows*, and 500 *breeding bulls*. The flows between these stocks drive the process from *being born* until becoming *dairy cows* or *breeding bulls*. During each stage of the maturation process some animals die due to disease, or are culled due to undesired characteristics. All male calves are sold after one year except for 2% that are kept for breeding purposes. Dairy cows are also sold on occasions if there is not enough fodder to feed all animals, which is denoted by the variable *effect of feed on net purchasing rate* (the

[7] Italized words are represented in the model

interconnections between the different modules are illustrated by using shadow (copy) variables with the respective color of each of the four modules). The decision to sell or buy dairy cows is also influenced by whether long-term profits are higher than expected over time. Long-run decision making is considered to be over a three year time horizon. Where profits are greater than expected, we assume that farmers will buy dairy cows, while if profits are negative over time relative to expectations we assume farmers will sell dairy cows. The amount of feed available per head of cattle also affects the *birth rate*, *mortality rate*, and *maturing delay*. The flows in this section of the model is measured in cows per week.

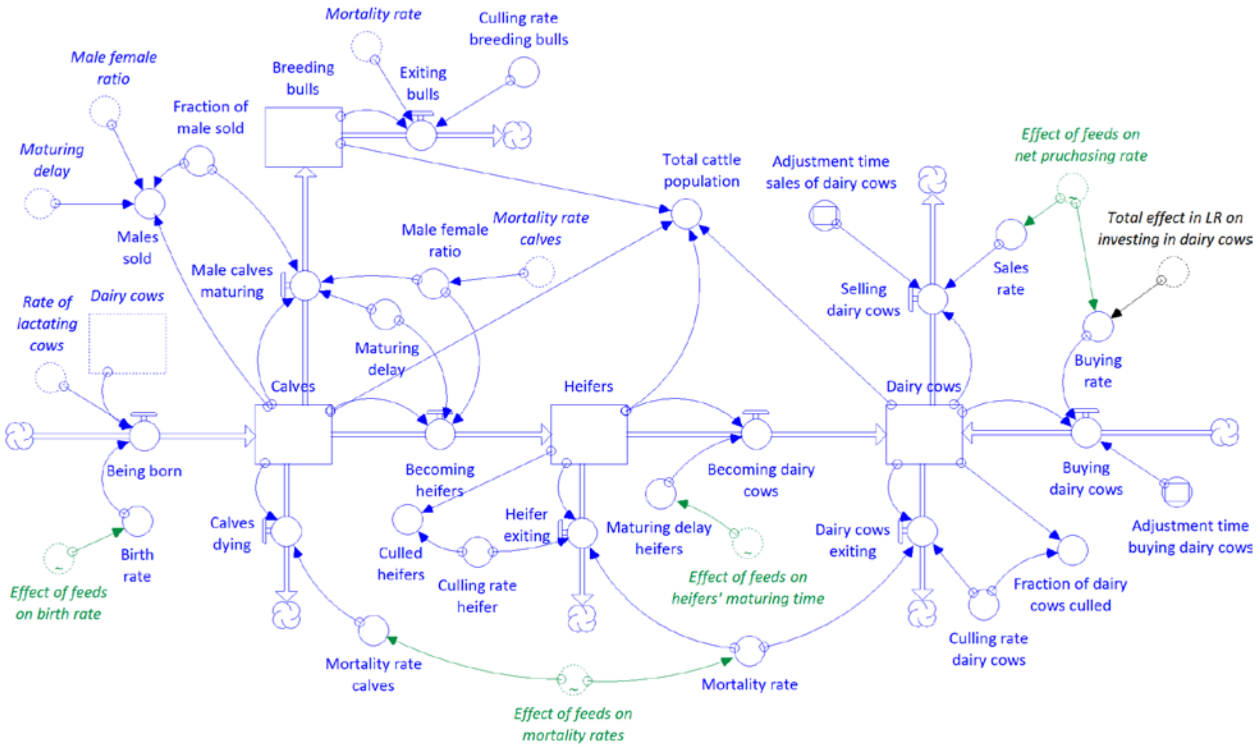


Figure A.1: Structure of the herd module. Source: Developed by the authors

Milk module

The milk module, illustrated in Figure A.2, consists of a sole stock of *producers' milk inventory*. The flow of milk production represents how much milk Matiguás dairy farmers produce per week, on average 450,000 kg. This is measured by multiplying the number of *dairy cows* by the *milk amount per cow* and the *rate of lactating cows*, which is 55% meaning not all cows produce milk at all times due to some being dry for breeding purposes. *Milk amount per cow* is influenced by the *predicted cow productivity*, which is the multiplication of average cow productivity, five liters per dairy cow per day, and the *effect of feed on cow productivity*. The variable *effect of feed on cow productivity* is responsible for seasonalizing milk production since there is lower feed availability in the dry season which consequently reduces the amount of milk produced per dairy cow per week. Further downstream in the value chain, 2.5% of producers' milk inventory is consumed at home. Of the remaining amount, 60% is collected by the cooperative, and the rest supplied to the informal sector. Processors in Managua control the demand for milk through cooperatives. If the demand for milk falls, the collection rate by the cooperative goes down, and more is sold in the informal sector. There is no set limit on the amount that can be supplied, so if milk production increases it is absorbed by the two sectors at a 60-40 rate unless changes are made to demand from processors (slider function).

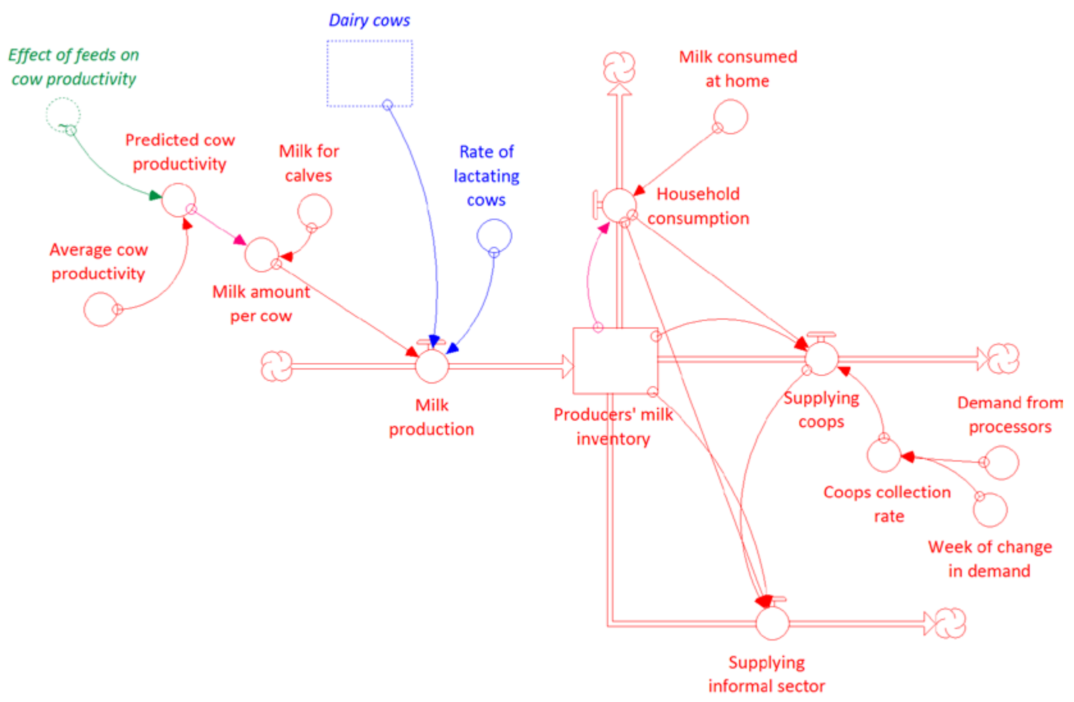


Figure A.2: Structure of the milk processing and sales module. Source: Developed by the authors

Feed module

The feed module, seen in Figure A.3, has the most complex structure in the model, because this is where the interventions and policy changes are implemented. The key building block is the stock *feed availability*. Feed availability is measured as the amount of protein produced in kg per week. Protein is used as the metric of measurement for feed since protein is the most limiting factor for milk production. Many types or large quantities of dry matter of feed could be available, but if the quality is low (in protein terms) it will not lead to high milk production. This is also the reason for complementing grazing with concentrates, which has a high rate of protein. All feed-related aspects of the feed module are therefore measured in kg of protein, either produced per manzana of land per week, or per kg of concentrate, or per head of cattle.

Three types of feed are produced by Matiguás farmers: *improved pasture, traditional pasture,* and *cut and carry* grasses. About 41% of land is used for improved pasture, with 53% devoted to traditional pasture, and cut and carry grasses 5%. Changing between the two types of pasture is influenced by a higher or lower than expected profit over the medium-term. Medium term is in this case considered to be 26 weeks, half a year. We assume that if farmers experience higher profits than expected over the medium run, they will invest in changing land used from traditional pasture to improved pasture. The total amount of land is constant since there is limited supply of land available, hence the focus on intensification. A change delay of nine months (36 weeks) represents the time it takes to switch from traditional to improved pasture. Each feed type persist of different seasonal productivity. Improved pasture is also of higher quality than traditional pasture. This is included in the model by using graphical functions that indicates the productivity per week during the year. If *drought* occurs the productivity of traditional pasture falls during the dry season (week 1-23) by 50% (scenario parameters are provided in the color purple). The reference group assumes that productivity of improved pasture and cut and carry grasses only reduces by 30%, which is an incentive to invest in these technologies since drought is becoming more common. Productivity of improved pasture also depends on the *increase in knowledge about improved pasture (IP) management* by farmers. This is elaborated in a separate structure, see Figure A.4, illustrating a scenario where farmers increase their knowledge through training. This part of the model is the only section that was not developed during the GMB process.

Concentrates, expressed in kg of protein per week, is a way of complementing grazing (produced feed). In the model, concentrates are bought when there is a *protein gap*. Purchasing concentrate is expensive and therefore depends on farmer profitability in the short run, two weeks, and is only given to lactating cows to boost milk production. The amount of concentrates and amount of produced feed available per head combine to form the most important effect in the model: *effect of feed on cow productivity*. Produced feed per head affects the birth rate, mortality rate, purchasing rate, all found in the herd module. Concentrate is not included in these effects since concentrate is used over the short term and has little effect on long term behaviors.

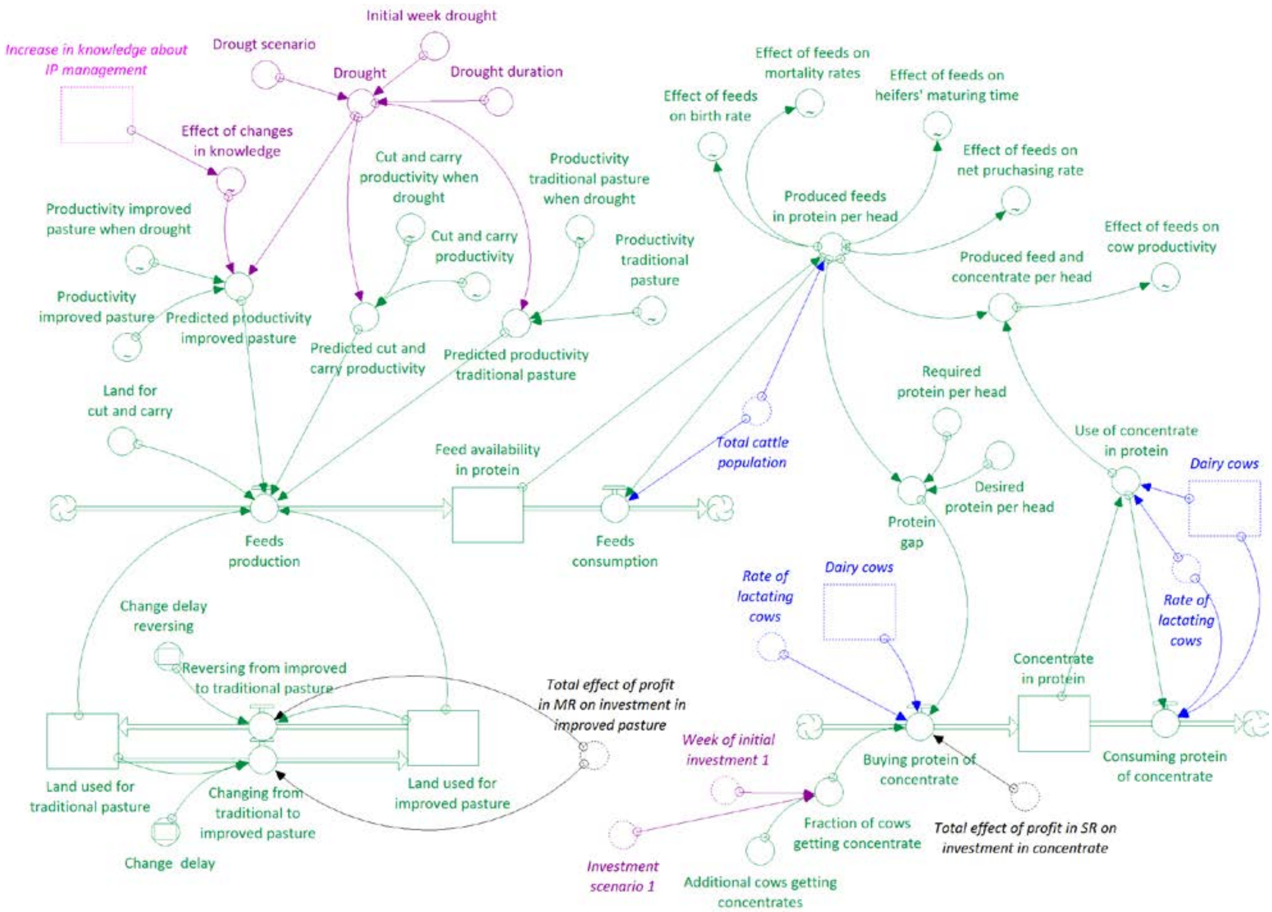


Figure A.3: Structure of feed module. Source: Developed by the authors

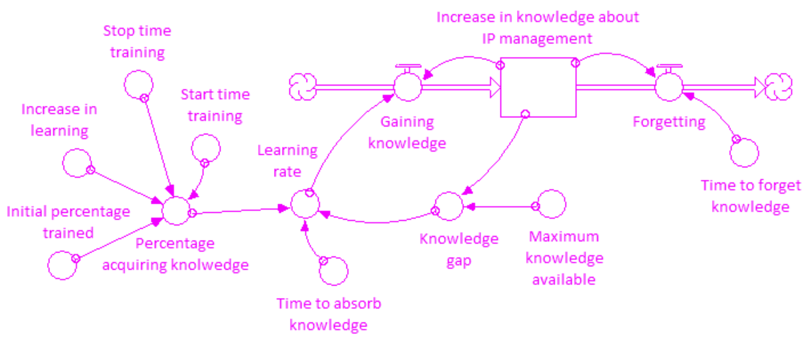


Figure A.4: Structure of learning about improved pasture management. Source: Developed by the authors

Finance module

The finance module consists of one structure that collects the costs and revenues from the three other modules, illustrated in Figure A.5. The second structure, illustrated in Figure A.6, transforms this information into investment decisions, such as investing in improved pasture or buying dairy cows. Milk prices are exogenous in the model because it is unlikely that local dairy producers will heavily influence the milk prices set by the industry actors in the capital. Seasonal price variations are included through the use of graphical functions. The highest price gap is in the informal sector, with a range from 8-13 NIO per kg of milk. In the formal sector, it only ranges between 11-12 NIO per kg of milk. Milk prices can be varied to shock the model. Price differentiation between different quality milk is not included in the model.

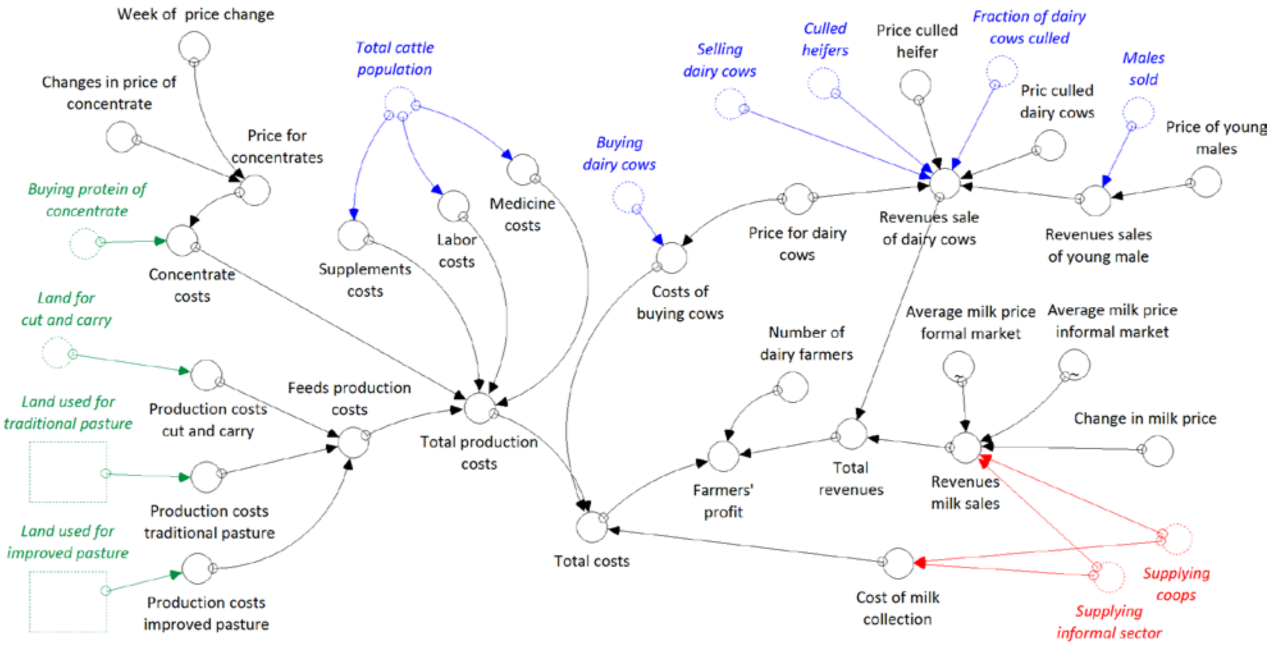


Figure A.5: Costs and revenue structure. Source: Developed by the authors

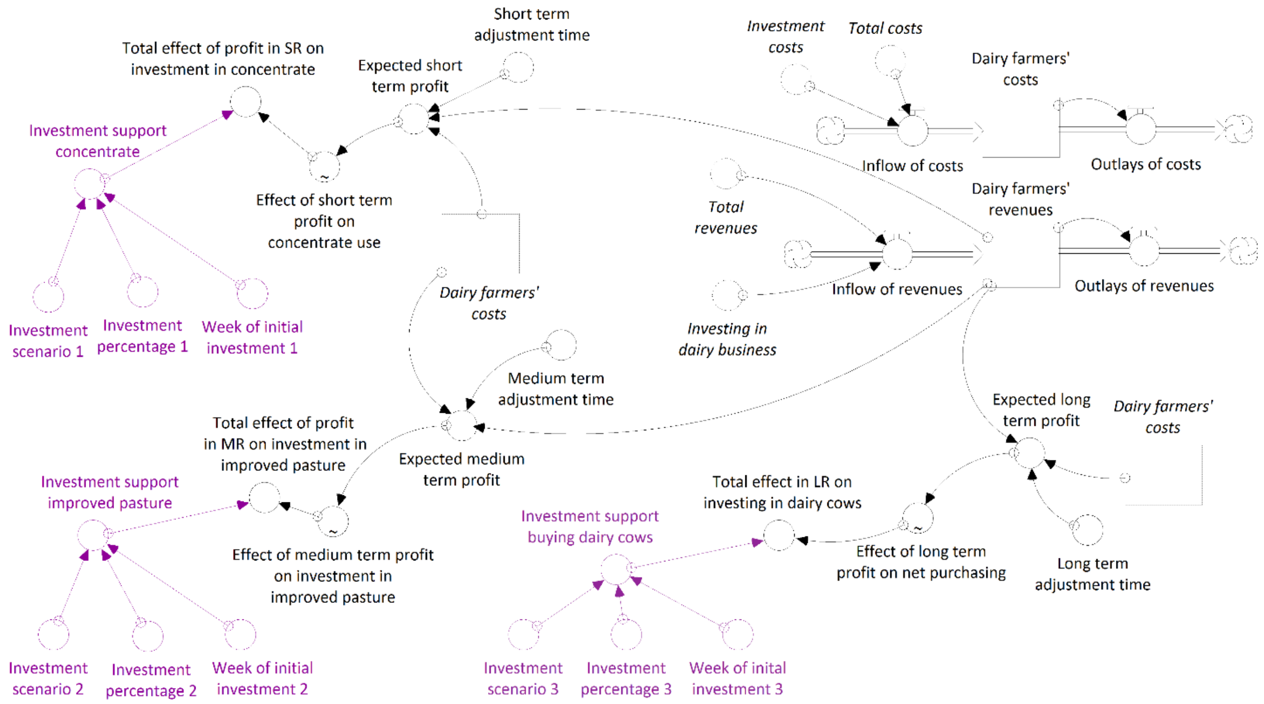


Figure A.6: Investment dynamics structure. Source: Developed by the authors

In the description of the previous modules, assumptions about short-, medium- and long run investments is mentioned. We assume that if Matiguás producers have higher than expeted short term (two weeks) profitability they will spend it on concentrates if there is a protein gap (scenario 1). If they have medium run (26 weeks) profitability higher than expected, they will invest in improved pasture (scenario 2). In the long run (156 weeks), farmers with higher than expected profitability will invest in purchasing dairy cows (scenario 3). In other words, different investment decicions are endogenously determined in the model based on expected profits. Additionally, it is possible to run simulations with each of these scenarios where investment decisions are exogenously determined based on potential value chain policies and interventions. The relative size of the investment can be set, as well as the week the investment starts.

Appendix B: Baseline date

Herd module	Baseline	Unit	Source
Stocks			
Calves	10000	Cow	Census MAGFOR 2011/GMB
Heifer	5000	Cow	Census MAGFOR 2011/GMB
Dairy cows	20000	Cow	Census MAGFOR 2011/GMB
Breeding bulls	500	Cow	Census MAGFOR 2011/GMB
Variables			
Birth rate	(0.66*Effect_of_feeds_on_birth_rate)/52	Cow/week	GMB
Rate of lactating cows	0.55 (Slider 0-1)	Unitless	Reference group
Mortality rate calves	(0.05*Effect_of_feeds_on__mortality_rates)/52	Cow/week	MAGFOR 2013/GMB
Male to female ratio	0.5*(1-Mortality_rate_calves)	Unitless	GMB
Maturing delay	52	Weeks	GMB
Maturing delay heifer	114*Effect_of_feeds_on_heifers'_maturing_time	Weeks	GMB4
Mortality rate	(0.03*Effect_of_feeds_on__mortality_rates)/52	Unitless	MAGFOR 2013/GMB
Culling rate heifer	0.02/52	Unitless	GMB4
Culling rate dairy cows	0.03/52	Unitless	GMB
Adjustment time sales of dairy cows	16	Weeks	Assumption
Adjustment time buying dairy cows	16	Weeks	Assumption
Fraction of males sold	0.95	Unitless	GMB
Sales delay (male calves)	12	Weeks	GMB
Culling rate breeding bulls	0.1	Unitless	GMB

Milk module	Baseline	Unit	Source
Stocks			
Producers' inventory	350000	kg	GMB
Variables			
Average cow productivity	5 (Slider 0-10)	kg/cow	GMB
Rate of lactating cows	0.55	Unitless	Reference group/GMB
Milk consumed at home	0.025	Unitless	GMB
Milk for calves	2.5	kg	GMB
Coop collection rate	IF Week_of_change_in_demand > 1 THEN 0.6 + STEP((0.60*Demand_from_processors-0.6), Week_of_change_in_demand) ELSE 0.60	Unitless	GMB
Demand from processors	1 (Slider 0-1.7)	Unitless	Scenario function
Week of change in demand	0 (Slider 0-520)	Unitless	Scenario function

Increase in IP knowledge	Baseline	Unit	Source
Stocks			
Increase in knowledge about IP management	0.001	Knowledge	Assumption
Variables			
Stop time training	0 (slider 0-520)	Week	Assumption
Start time training	1 (slider 0-520)	Week	Assumption
Initial percentage trained	0 (slider 0-1)	Week	Assumption
Time to absorb knowledge	29	Weeks	Assumption
Maximum knowledge available	1	Knowledge	
Time to forget knowledge	156	Weeks	Assumption

Feeds module	**Baseline**	**Unit**	**Source**
Stocks			
Feed availability	200000	Protein	Estimate
Land in use for traditional pasture	21060	Manzana	Census MAGFOR 2011
Land in use for improved pasture	16200	Manzana	Census MAGFOR 2011
Concentrate in protein	0	Protein	
Variables			
Land for CC	2025	Manzana	Census MAGFOR 2011
Change delay	36	Weeks	Reference group
Change delay reversing	156	Weeks	Reference group
Required protein per head	8	Protein/cow	Reference group
Desired protein per head	Slider 8-16	Protein/cow	Reference group
Fraction of cows getting concentrate	IF Investment_scenario_1= 1 THEN (0.2 + STEP (Additional_cows_getting_concentrates, Week_of_initial_investment_1)) ELSE 0.2	Cows/week	GMB
Additional cows getting concentrates	0 (slider 0-1)		
Drought scenario	0 (Switch 0=off, 1=on)	Unitless	Scenario function
Productivity reduction improved pasture	0.3	Unitless	Reference group
Productivity reduction traditional pasture	0.5	Unitless	Reference group
Drought duration	0 (slider 0-520)	Week	Scenario function
Initial week drought	0 (slider 0-520)	Week	Scenario function

Costs and revenues	**Baseline**	**Unit**	**Source**
Production costs traditional pasture	1350/52*Land_used_for_traditional_pasture	NIO/manzana	CIAT calculations
Production costs improved pasture	2000/52*Land_used_for__improved_pasture	NIO/manzana	CIAT calculations
Production costs cut and carry	4500/52*Land_for__cut_and_carry	NIO/manzana	CIAT calculations
Medicine costs	(340*Total_cattle_population)/52	NIO/week	GMB
Labor costs	((4000*12)*(Total_cattle_population/15))/52	NIO/week	Reference group
Supplement costs	(Total_cattle_population*762)/52	NIO/week	GMB
Cost of milk collection	Supplying_coops+Supplying_informal_sector*1	NIO/kg	GMB
Price of concentrate	56	NIO/kg	GMB
Changes in price for concentrates	1 (slider 0-2)	Unitless	Scenario function
Week of price change	0 (slider 1-520)	Week	Scenario function
Price of young males	5000	NIO/cow	GMB
Price dairy cows	19000	NIO/cow	GMB
Price culled heifer	12500	NIO/cow	GMB
Price culled dairy cows	15500	NIO/cow	GMB
Number of dairy farmers (households)	1680	Farmer	MAGFOR 2013

Investment dynamics	**Baseline**	**Unit**	**Source**
Stocks			
Dairy farmers' costs	1	NIO	Scenario function
Dairy farmers revenues	1	NIO	Scenario function
Investment	0	NIO	Scenario function
Variables			
Short term adjustment time	2	Week	Reference group
Medium term adjsutment time	26	Week	Reference group
Lon term adjsutment time	156	Week	Reference group

Appendix C: Model equations

Herd module	Equations	Unit
Being born	Dairy_cows*Birth_rate*(1-Rate_of_lactating_cows)	Cows/week
Calves dying	Calves*Mortality_rate_calves	Cows/week
Male calves sold	((Calves*Male_female_ratio)/Maturing_delay)*Fraction_of__male_sold	Cows/week
Becoming heifers	(Calves*Male_female_ratio)/Maturing_delay	Cows/week
Heifer exiting	Heifers*(Mortality_rate+Culling_rate_heifer)	Cows/week
Becoming dairy cows	Heifers/Maturing_delay_heifers	Cows/week
Buying dairy cows	DELAY((Dairy_cows*Buying__rate), Adjustment_time_buying_dairy_cows)	Cows/week
Dairy cows exiting	(Dairy_cows*(Mortality_rate+Culling_rate__dairy_cows))	Cows/week
Selling dairy cows	DELAY((Dairy_cows*Sales_rate), Adjustment_time_sales_of_dairy_cows)	Cows/week
Males sold	((Calves*Male_female_ratio)/Maturing_delay)*Fraction_of__male_sold	Cows/week
Exiting bulls	Breeding_bulls*(Culling_rate_breeding_bulls+Mortality_rate)	Cows/week
Sales rate (dairy cows)	if Effect_of_feeds_on_net_pruchasing_rate<0 then ((1+Effect_of_feeds_on_net_pruchasing_rate)/52) else 0	Cows/week
Buying rate (dairy cows)	if Effect_of_feeds_on_net_pruchasing_rate>0 then ((Effect_of_feeds_on_net_pruchasing_rate+Total_effect_in_LR_on_investing_in_dairy_cows)/ 52) else 0	Cows/week
Total cattle population	Calves+Heifers+Dairy_cows+Breeding_bulls	Cows/week
Males sold	DELAY ((Male_calves_maturing*Fraction_of__male_sold), Sales_delay)	Cows/week
Fraction of dairy cows culled	Dairy_cows*Culling_rate__dairy_cows	Cows/week
Culled heifers	Heifers*Culling_rate_heifer	Cows/week

Milk module	Equations	Unit
Milking amount	if Predicted_cow_productivity<10 then (Predicted_cow_productivity*0.75) else (Predicted_cow_productivity- Milk_for_calves)	Kg/week
Predicted cow productivity	Effect_of_feeds_on_cow_productivity*Average_cow_productivity	Kg/cow
Milk production	SMTH1((Milking_amount*Dairy_cows*Rate_of_lactating_cows*7), Adjustment_time_milk_proc	Kg/week
Supplying coops	(Producers_milk_inventory-Household_consumption)*Coops_collection__rate	Kg/week
Supplying informal sector	Producers_milk_inventory-Household_consumption-Supplying_coops	Kg/week
Household consumption	Milk_consumed_at_home	Kg/week

Increase in IP knowledge	Equations	Unit
Gaining knowledge	Increase_in_knowledge_about_IP_management*Learning_rate	Knowledge/week
Forgetting	Increase_in_knowledge_about_IP_management/Time_to_forget_knowledge	Knowledge/week
Learning rate	Knowledge__gap*Percentage_acquiring_knolwedge/Time_to_absorb_knowledge	Unitless
Percentage aquiring knowledge	MIN(Initial_percentage_trained+RAMP(Increase_in__learning, Start_time_training)-RAMP(Increase_in__learning, Stop_time_training), 1)	Manzana
Knowledge gap	Maximum__knowledge_available-Increase_in_knowledge_about_IP_management	Knowledge

Feed module	Equations	Unit
Feeds production	(Land_for__cut_and_carry*(Predicted_cut_and__carry_productivity))+(Land_used_for_traditional_pasture*(Predicted_productivity_traditional_pasture))+(Land_used_for__improved_pasture*(Predicted_productivity_improved_pasture))	Protein/week
Feeds consumption	Produced_feeds__in_protein_per_head*Total_cattle_population	Protein/week
Changing from traditional to improved pasture	if Total_effect_of_profit_in_MR_on_investment_in__improved_pasture>0 then((Land_used_for_traditional_pasture*Total_effect_of_profit_in_MR_on_investment_in__improved_pasture))/Change__delay else 0	Manzana/week
Reversing from improved pasture to traditional pasture	if Total_effect_of_profit_in_MR_on_investment_in__improved_pasture<0 then ((Land_used_for__improved_pasture*Total_effect_of_profit_in_MR_on_investment_in__improved_pasture)/Change_delay_reversing) else 0	Manzana/week
Buying protein of concentrate	if Protein_gap>0 then Protein_gap*(Dairy_cows*Rate_of__lactating_cows)*(Fraction_of_cows_getting_concentrate+Total_effect_of_profit_in_SR_on_investment_in_concentrate) else 0	Protein/week
Consuming protein of concentrate	Use_of_concentrate_in_protein*(Dairy_cows*Rate_of__lactating_cows)	Protein/week
Predicted cut and carry productivity	IF Drought = 1 THEN Cut_and_carry_productivity_when_drought else Cut_and_carry_productivity	Protein/manzana
Predicted productivity improved pasture	IF Drought = 1 THEN Productivity_improved__pasture_when_drought else (Productivity_improved__pasture*Learning_effect)	Protein/manzana
Predicted productivity traditional pasture	IF Drought = 1 THEN Productivity__traditional_pasture___when_drought ELSE Productivity_traditional_pasture	Protein/manzana
Productivity improved pasture	Productivity_improved__pasture = GRAPH(TIME) (1.00, 8.00), (2.00, 8.00), (3.00, 8.00), (4.00, 7.00), (5.00, 7.00), (6.00, 6.00), (7.00, 6.00), (8.00, 6.00), (9.00, 6.00), (10.0, 6.00), (11.0, 5.00), (12.0, 5.00), (13.0, 5.00), (14.0, 5.00), (15.0, 5.00), (16.0, 5.00), (17.0, 5.00), (18.0, 5.00), (19.0, 7.00), (20.0, 7.00), (21.0, 8.00), (22.0, 8.00), (23.0, 9.00), (24.0, 11.0), (25.0, 12.0), (26.0, 12.0), (27.0, 13.0), (28.0, 14.0), (29.0, 15.0), (30.0, 16.0), (31.0, 15.0), (32.0, 15.0), (33.0, 15.0), (34.0, 14.0), (35.0, 14.0), (36.0, 13.0), (37.0, 13.0), (38.0, 13.0), (39.0, 12.0), (40.0, 12.0), (41.0, 11.0), (42.0, 11.0), (43.0, 11.0), (44.0, 10.0), (45.0, 10.0), (46.0, 9.00), (47.0, 9.00), (48.0, 9.00), (49.0, 8.00), (50.0, 8.00), (51.0, 8.00), (52.0, 8.00), (53.0, 8.00)...	Protein/manzana
Productivity traditionl pasture	Productivity_traditional_pasture = GRAPH(TIME) (0.00, 3.00), (1.00, 3.00), (2.00, 3.00), (3.01, 3.00), (4.01, 3.00), (5.01, 3.00), (6.01, 3.00), (7.01, 2.00), (8.02, 2.00), (9.02, 2.00), (10.0, 2.00), (11.0, 1.00), (12.0, 1.00), (13.0, 1.00), (14.0, 1.00), (15.0, 1.00), (16.0, 1.00), (17.0, 1.00), (18.0, 3.00), (19.0, 4.00), (20.0, 5.00), (21.0, 6.00), (22.0, 7.00), (23.0, 7.00), (24.0, 8.00), (25.0, 9.00), (26.1, 10.0), (27.1, 11.0), (28.1, 11.0), (29.1, 12.0), (30.1, 12.0), (31.1, 12.0), (32.1, 11.0), (33.1, 11.0), (34.1, 11.0), (35.1, 9.00), (36.1, 8.00), (37.1, 8.00), (38.1, 8.00), (39.1, 7.00), (40.1, 7.00), (41.1, 7.00), (42.1, 7.00), (43.1, 6.00), (44.1, 6.00), (45.1, 6.00), (46.1, 6.00), (47.1, 4.00), (48.1, 4.00), (49.1, 4.00), (50.1, 4.00), (51.1, 3.00), (52.1, 3.00)...	Protein/manzana
Cut and carry productivity	Cut_and_carry_productivity = GRAPH(TIME) (1.00, 32.0), (2.00, 32.0), (3.00, 32.0), (4.00, 29.0), (5.00, 29.0), (6.00, 29.0), (7.00, 29.0), (8.00, 29.0), (9.00, 29.0), (10.0, 29.0), (11.0, 29.0), (12.0, 25.0), (13.0, 25.0), (14.0, 25.0), (15.0, 25.0), (16.0, 25.0), (17.0, 25.0), (18.0, 25.0), (19.0, 25.0), (20.0, 0.00), (21.0, 0.00), (22.0, 0.00), (23.0, 0.00), (24.0, 0.00), (25.0, 0.00), (26.0, 0.00), (27.0, 0.00), (28.0, 0.00), (29.0, 0.00), (30.0, 0.00), (31.0, 0.00), (32.0, 0.00), (33.0, 0.00), (34.0, 0.00), (35.0, 0.00), (36.0, 0.00), (37.0, 0.00), (38.0, 0.00), (39.0, 0.00), (40.0, 0.00), (41.0, 0.00), (42.0, 0.00), (43.0, 0.00), (44.0, 0.00), (45.0, 0.00), (46.0, 0.00), (47.0, 0.00), (48.0, 0.00), (49.0, 0.00), (50.0, 0.00), (51.0, 0.00), (52.0, 0.00), (53.0, 32.0)...	Protein/manzana
Productivity traditional pasture when drought	Productivity__traditional_pasture___when_drought = GRAPH(TIME) (0.00, 1.50), (1.00, 1.50), (2.00, 1.50), (3.01, 1.50), (4.01, 1.50), (5.01, 1.50), (6.01, 1.50), (7.01, 1.00), (8.02, 1.00), (9.02, 1.00), (10.0, 1.00), (11.0, 0.5), (12.0, 0.5), (13.0, 0.5), (14.0, 0.5), (15.0, 0.5), (16.0, 0.5), (17.0, 0.5), (18.0, 1.50), (19.0, 2.00), (20.0, 2.50), (21.0, 3.00), (22.0, 3.50), (23.0, 7.00), (24.0, 8.00), (25.0, 9.00), (26.1, 10.0), (27.1, 11.0), (28.1, 11.0), (29.1, 12.0), (30.1, 12.0), (31.1, 12.0), (32.1, 11.0), (33.1, 11.0), (34.1, 11.0), (35.1, 9.00), (36.1, 8.00), (37.1, 8.00), (38.1, 8.00), (39.1, 7.00), (40.1, 7.00), (41.1, 7.00), (42.1, 7.00), (43.1, 6.00), (44.1, 6.00), (45.1, 6.00), (46.1, 6.00), (47.1, 4.00), (48.1, 4.00), (49.1, 4.00), (50.1, 4.00), (51.1, 3.00), (52.1, 1.50)...	Protein/manzana
Productivity improved pasture when drought	Productivity_improved__pasture_when_drought = GRAPH(TIME) (1.00, 5.60), (2.00, 5.60), (3.00, 5.60), (4.00, 4.90), (5.00, 4.90), (6.00, 4.20), (7.00, 4.20), (8.00, 4.20), (9.00, 4.20), (10.0, 4.20), (11.0, 3.50), (12.0, 3.50), (13.0, 3.50), (14.0, 3.50), (15.0, 3.50), (16.0, 3.50), (17.0, 3.50), (18.0, 3.50), (19.0, 4.90), (20.0, 4.90), (21.0, 5.60), (22.0, 5.60), (23.0, 6.30), (24.0, 11.0), (25.0, 12.0), (26.0, 12.0), (27.0, 13.0), (28.0, 14.0), (29.0, 15.0), (30.0, 16.0), (31.0, 15.0), (32.0, 15.0), (33.0, 15.0), (34.0, 14.0), (35.0, 14.0), (36.0, 13.0), (37.0, 13.0), (38.0, 13.0), (39.0, 12.0), (40.0, 12.0), (41.0, 11.0), (42.0, 11.0), (43.0, 11.0), (44.0, 10.0), (45.0, 10.0), (46.0, 9.00), (47.0, 9.00), (48.0, 9.00), (49.0, 8.00), (50.0, 8.00), (51.0, 8.00), (52.0, 8.00), (53.0, 5.60)...	Protein/manzana
Cut and carry productivity when drought	Cut_and_carry_productivity_when_drought = GRAPH(TIME) (1.00, 22.0), (2.00, 22.0), (3.00, 22.0), (4.00, 20.0), (5.00, 20.0), (6.00, 20.0), (7.00, 20.0), (8.00, 20.0), (9.00, 20.0), (10.0, 20.0), (11.0, 20.0), (12.0, 20.0), (13.0, 17.0), (14.0, 17.0), (15.0, 17.0), (16.0, 17.0), (17.0, 17.0), (18.0, 17.0), (19.0, 17.0), (20.0, 0.00), (21.0, 0.00), (22.0, 0.00), (23.0, 0.00), (24.0, 0.00), (25.0, 0.00), (26.0, 0.00), (27.0, 0.00), (28.0, 0.00), (29.0, 0.00), (30.0, 0.00), (31.0, 0.00), (32.0, 0.00), (33.0, 0.00), (34.0, 0.00), (35.0, 0.00), (36.0, 0.00), (37.0, 0.00), (38.0, 0.00), (39.0, 0.00), (40.0, 0.00), (41.0, 0.00), (42.0, 0.00), (43.0, 0.00), (44.0, 0.00), (45.0, 0.00), (46.0, 0.00), (47.0, 0.00), (48.0, 0.00), (49.0, 0.00), (50.0, 0.00), (51.0, 0.00), (52.0, 0.00), (53.0, 22.0)...	Protein/manzana

Protein gap	if Desired_protein>8 then (Desired_protein-Produced_feeds__in_protein_per_head) else (Required_protein_per_head-Produced_feeds__in_protein_per_head)	Protein
Effect of feeds on net purchasing rate	Effect_of_feeds_on_net_pruchasing_rate = GRAPH(Produced_feeds__in_protein_per_head) (0.00, -1.00), (1.60, -0.6), (3.20, -0.2), (4.80, 0.00), (6.40, 0.00), (8.00, 0.00), (9.60, 0.00), (11.2, 0.00), (12.8, 0.2), (14.4, 0.4), (16.0, 0.8)	Unitless
Effect of feeds on birth rate	Effect_of_feeds_on_birth_rate = GRAPH(Produced_feeds__in_protein_per_head) (0.00, 0.4), (2.00, 0.6), (4.00, 0.8), (6.00, 1.00), (8.00, 1.10), (10.0, 1.20), (12.0, 1.20), (14.0, 1.20), (16.0, 1.20)	Unitless
Effect of feeds on mortality rates	Effect_of_feeds_on__mortality_rates = GRAPH(Produced_feeds__in_protein_per_head) (0.00, 2.00), (2.00, 1.70), (4.00, 1.30), (6.00, 1.00), (8.00, 0.8), (10.0, 0.7), (12.0, 0.7), (14.0, 0.7), (16.0, 0.7)	Unitless
Effect of feeds on heifers' maturing time	Effect_of_feeds_on_heifers'_maturing_time = GRAPH(Produced_feeds__in_protein_per_head) (0.00, 1.35), (2.00, 1.35), (4.00, 1.20), (6.00, 1.00), (8.00, 0.8), (10.0, 0.55), (12.0, 0.55), (14.0, 0.55), (16.0, 0.55)	Unitless
Produced feeds in protein per head	Feed_availability_in_protein/Total_cattle_population	Protein
Effect of feeds on cow productivity	Effect_of_feeds_on_cow_productivity = GRAPH(Produced_feed_and__concentrate_per_head) (0.00, 0.00), (2.00, 0.5), (4.00, 1.00), (6.00, 1.40), (8.00, 1.80), (10.0, 2.00), (12.0, 2.00), (14.0, 2.00), (16.0, 2.00)	Unitless
Use of concentrate in protein	Concentrate_in_protein/(Dairy_cows*Rate_of__lactating_cows)	Protein/Cow
Effect of drought on improved pasture	if Drought_scenario =1 then (step(Productivity_reduction_improved_grasses,1) + step (-Productivity_reduction_improved_grasses, 23)) else 0	Unitless
Effect of drought on traditional pasture	if Drought_scenario =1 then (step(Productivty_reduction_trad_pasture,1) + step (-Productivty_reduction_trad_pasture, 23)) else 0	Unitless
Effect of changes in knowledge	Effect_of_changes_in_knowledge = GRAPH(Increase_in_knowledge_about_IP_management) (0.00, 0.8), (0.1, 0.82), (0.2, 0.84), (0.3, 0.86), (0.4, 0.88), (0.5, 0.9), (0.6, 0.92), (0.7, 0.94), (0.8, 0.96), (0.9, 0.98), (1.00, 1.00)	Unitless

Costs and revenues	**Equations**	**Unit**
Total production costs	Feeds_production_costs+Supplements_costs+Labor__costs+Medicine_costs+Concentrate_costs	Cordoba/week
Feeds production costs	Production_costs_traditional_pasture+Production_costs_improved_pasture+Production_costs_cut_and_carry	Cordoba/week
Concentrate costs	Buying_protein_of__concentrate*Price_of__concentrate	Cordoba/week
Total costs	Total_production_costs+Costs_of__buying_cows+Cost_of_milk_collection	Cordoba/week
Costs of buying cows	Price_for_dairy_cows*Buying__dairy_cows	Cordoba/week
Revenues sale of dairy cows	(Fraction_of_dairy__cows_culled*Pric_culled_dairy_cows)+(Culled_heifers*Price_culled_heifer)+(Selling__dairy_cows*Price_for_dairy_cows)+Revenues_sales_of_young_male	Cordoba/week
Revenues sales of young males	Males_sold*Price_of_young_males	Cordoba/week
Total revenues	Revenues_sale_of_dairy_cows+Revenues_milk_sales	Cordoba/week
Revenues milk sales	(Supplying_informal_sector*(Average_milk_price_informal_market*Change_in_price))+(Supplying_coops*(Average_milk_price_formal_market*Change_in_price))	Cordoba/week
Average milk price formal market	Average_milk_price_formal_market = GRAPH(TIME) (1.00, 12.0), (2.00, 12.0), (3.00, 12.0), (4.00, 12.0), (5.00, 12.0), (6.00, 12.0), (7.00, 12.0), (8.00, 12.0), (9.00, 12.0), (10.0, 12.0), (11.0, 12.0), (12.0, 12.0), (13.0, 12.0), (14.0, 12.0), (15.0, 12.0), (16.0, 12.0), (17.0, 12.0), (18.0, 12.0), (19.0, 12.0), (20.0, 12.0), (21.0, 12.0), (22.0, 12.0), (23.0, 12.0), (24.0, 12.0), (25.0, 11.0), (26.0, 11.0), (27.0, 11.0), (28.0, 11.0), (29.0, 11.0), (30.0, 11.0), (31.0, 11.0), (32.0, 11.0), (33.0, 11.0), (34.0, 11.0), (35.0, 11.0), (36.0, 11.0), (37.0, 11.0), (38.0, 11.0), (39.0, 11.0), (40.0, 11.0), (41.0, 11.0), (42.0, 11.0), (43.0, 11.0), (44.0, 11.0), (45.0, 11.0), (46.0, 11.0), (47.0, 11.0), (48.0, 11.0), (49.0, 11.0), (50.0, 11.0), (51.0, 11.0), (52.0, 11.0), (53.0, 12.0)...	Cordoba/kg
Average milk price informal market	Average_milk_price_informal_market = GRAPH(TIME) (1.00, 13.0), (2.00, 13.0), (3.00, 13.0), (4.00, 13.0), (5.00, 13.0), (6.00, 13.0), (7.00, 13.0), (8.00, 13.0), (9.00, 13.0), (10.0, 13.0), (11.0, 13.0), (12.0, 13.0), (13.0, 13.0), (14.0, 13.0), (15.0, 13.0), (16.0, 13.0), (17.0, 10.0), (18.0, 10.0), (19.0, 10.0), (20.0, 10.0), (21.0, 10.0), (22.0, 10.0), (23.0, 10.0), (24.0, 10.0), (25.0, 10.0), (26.0, 10.0), (27.0, 10.0), (28.0, 10.0), (29.0, 8.00), (30.0, 8.00), (31.0, 8.00), (32.0, 8.00), (33.0, 8.00), (34.0, 8.00), (35.0, 8.00), (36.0, 8.00), (37.0, 8.00), (38.0, 8.00), (39.0, 8.00), (40.0, 8.00), (41.0, 8.00), (42.0, 8.00), (43.0, 8.00), (44.0, 8.00), (45.0, 8.00), (46.0, 8.00), (47.0, 8.00), (48.0, 8.00), (49.0, 8.00), (50.0, 8.00), (51.0, 8.00), (52.0, 8.00), (53.0, 13.0)...	Cordoba/kg
Change in price	1 (slider 0-2)	Unitless
Farmers profit	SMTH1 ((Total_revenues-Total_costs)/Number_of__dairy_farmers, 4)	Cordoba/week

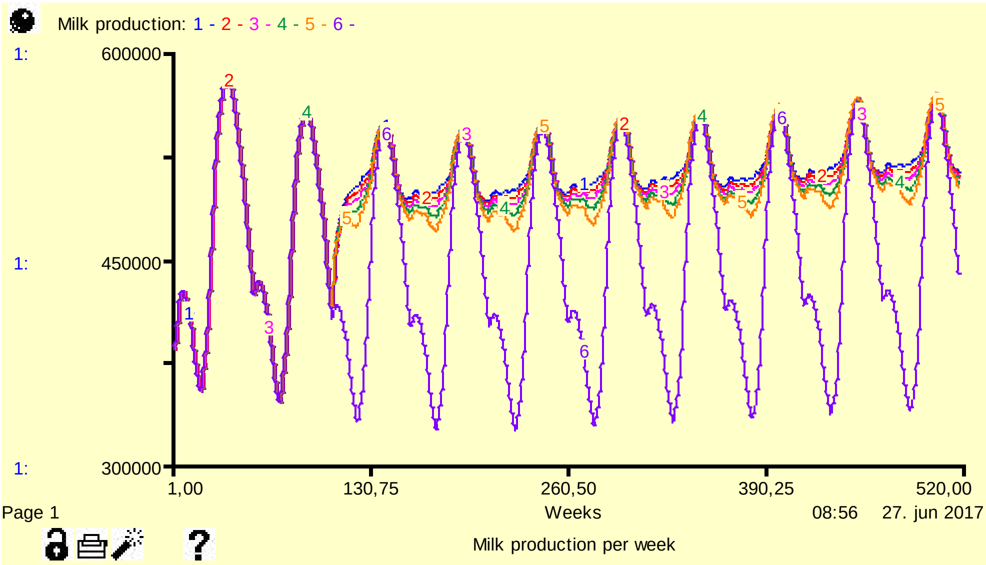
Investment dynamics	Equations	Unit
Inflow of costs	Total_costs+Investment_costs	Cordoba/week
Outlays of costs	pulse(Dairy_farmers'_costs,1,1)	Cordoba/week
Inflow of revenues	Total_revenues+Investing_in_dairy_business	Cordoba/week
Outlays of revenues	pulse(Dairy_farmers'_revenues,1,1)	Cordoba/week
Investment support concentrate	if Investment_scenario_1=1 then step(Investment_percentage_1,Week_of_initial_investment_1) else 0	Unitless
Investment scenario 1	0 (Swith 0=off, 1=on)	Unitless
Investment percentage 1	0 (Slider 0-1)	Unitless
Week of initial investment 1	1 (Slider 1-520)	Week
Total effect of profit in SR on investment in concentrate	Effect_of_short_term_profit_on_concentrate_use+Investment_support_concentrate	Unitless
Effect of short term profit on cencentrate use	Effect_of_short_term_profit_on_concentrate_use = GRAPH(Expected_short_term_profit) (-1.00, -1.00), (-0.9, -0.9), (-0.8, -0.8), (-0.7, -0.7), (-0.6, -0.6), (-0.5, -0.5), (-0.4, -0.4), (-0.3, -0.3), (-0.2, -0.2), (-0.1, -0.1), (0.00, 0.00), (0.1, 0.1), (0.2, 0.2), (0.3, 0.3), (0.4, 0.4), (0.5, 0.5), (0.6, 0.6), (0.7, 0.7), (0.8, 0.8), (0.9, 0.9), (1.00, 1.00)	Unitless
Expected short term profit	if Dairy_farmers'_revenues >0 then SMTH1(((Dairy_farmers'_revenues-Dairy_farmers'_costs)/Dairy_farmers'_revenues), Short_term_adjustment_time) else 0	Cordoba/week
Investment support improved pasture	if Investment_scenario_2=1 then step(Investment_percentage_2,Week_of_initial_investment_2)	Cordoba/week
Investment scenario 2	0 (Swith 0=off, 1=on)	Unitless
Investment percentage 2	0 (Slider 0-1)	Unitless
Week of initial investment 2	1 (Slider 1-520)	Week
Total effect of profit in MR on investment in improved pasture	Effect_of_medium_term_profit__on_investment_in_improved_pasture+Investment_support_imp	Unitless
Effect of medium term profit on investment in improved pasture	Effect_of_medium_term_profit__on_investment_in_improved_pasture = GRAPH(Expected_medium_term_profit) (-1.00, -0.3), (-0.9, -0.26), (-0.8, -0.22), (-0.7, -0.18), (-0.6, -0.14), (-0.5, -0.1), (-0.4, -0.06), (-0.3, -0.04), (-0.2, -0.02), (-0.1, 0.01), (0.00, 0.00), (0.1, 0.01), (0.2, 0.02), (0.3, 0.04), (0.4, 0.06), (0.5, 0.1), (0.6, 0.14), (0.7, 0.18), (0.8, 0.22), (0.9, 0.26), (1.00, 0.3)	Unitless
Expected medium term profit	if Dairy_farmers'_revenues>0 then SMTH1 (((Dairy_farmers'_revenues-Dairy_farmers'_costs)/Dairy_farmers'_revenues), Medium_term_adjustment_time) else 0	Cordoba/week
Investment support buying dairy cows	if Investment_scenario_3=1 then step(Investment_percentage_3,Week_of_inital_investment_3) else 0	
Investment scenario 3	0 (Swith 0=off, 1=on)	Unitless
Investment percentage 3	0 (Slider 0-1)	Unitless
Week of initial investment 3	1 (Slider 1-520)	Week
Total effect in LR on investing in dairy cows	Effect_of_long_term_profit_on_net_purchasing+Investment_support_buying_dairy_cows	Unitless
Effect of long term profit on net purchasing	Effect_of_long_term_profit_on_net_purchasing = GRAPH(Expected_long_term_profit) (-1.00, -0.2), (-0.9, -0.18), (-0.8, -0.16), (-0.7, -0.14), (-0.6, -0.12), (-0.5, -0.1), (-0.4, -0.08), (-0.3, -0.06), (-0.2, -0.04), (-0.1, -0.02), (0.00, 0.00), (0.1, 0.02), (0.2, 0.04), (0.3, 0.06), (0.4, 0.08), (0.5, 0.1), (0.6, 0.12), (0.7, 0.14), (0.8, 0.16), (0.9, 0.18), (1.00, 0.2)	Unitless
Expected long term profit	if Dairy_farmers'_revenues>0 then SMTH1(((Dairy_farmers'_revenues-Dairy_farmers'_costs)/Dairy_farmers'_revenues), Long_term_adjustment_time) else 0	Unitless
	Not included in paper	
Investing in dairy business	if Investment_scenario_4 = 1 THEN (STEP((Investment_amount_per_week*(Number_of__dairy_farmers*Fraction_of_farmers_investing)), Start_week_investment) + step ((-Investment_amount_per_week*(Number_of__dairy_farmers*Fraction_of_farmers_investing)), Start_week_investment+Investment_duration)) else 0	Cordoba/week
Investment costs	(Investment*Interest_rate)/Payback_time	Cordoba/week
Investment scenario 4	0 (Swith 0=off, 1=on)	Unitless
Fraction of farmers investing	0 (Slider 0-1)	Unitless
Start week investing	1 (Slider 1-520)	Unitless
Investment duration	0 (Slider 0-520)	Week
Investment amount per week	0 (Slider 0-2000)	Cordoba
Interest rate	0 (Slider 0-1)	Unitless
Payback time	0 (Slider 0-520)	Week

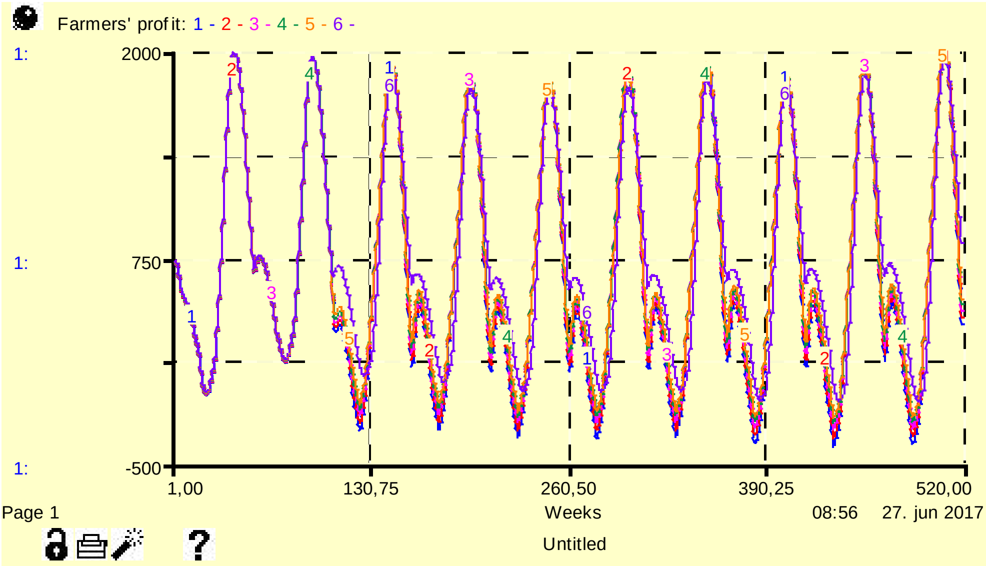
Appendix D: Sensitivity analysis investment percentage in scenarios 1-3

Scenario 1 investment sensitivity

The uncertainty of this parameter necessitated a sensitivity analysis of different options for investment percentages. The sensitivity analysis illustrates that all investment percentages, combined with a 50 percentage point increase in the fraction of dairy cows receiving concentrates, have substantial impact on milk production and farmer profit. We decided to choose a relatively high investment percentage of 20% to analyze farmer responsiveness to large amounts of concentrates and the level of price reduction needed to facilitate profitable concentrate use.

Simulation overview
1 = 0.25
2 = 0.2
3 = 0.15
4 = 0.1
5 = 0.05
6 = Baseline

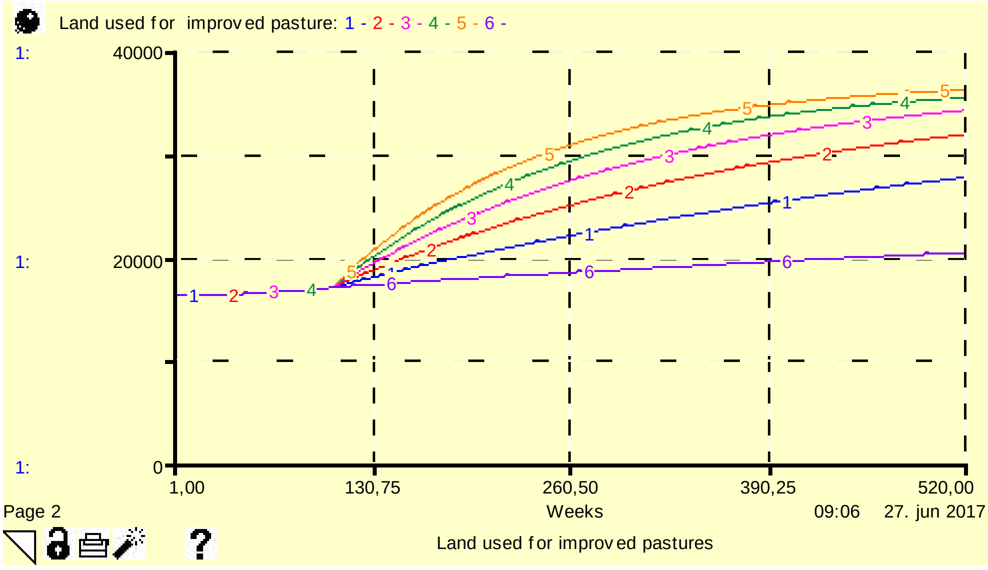


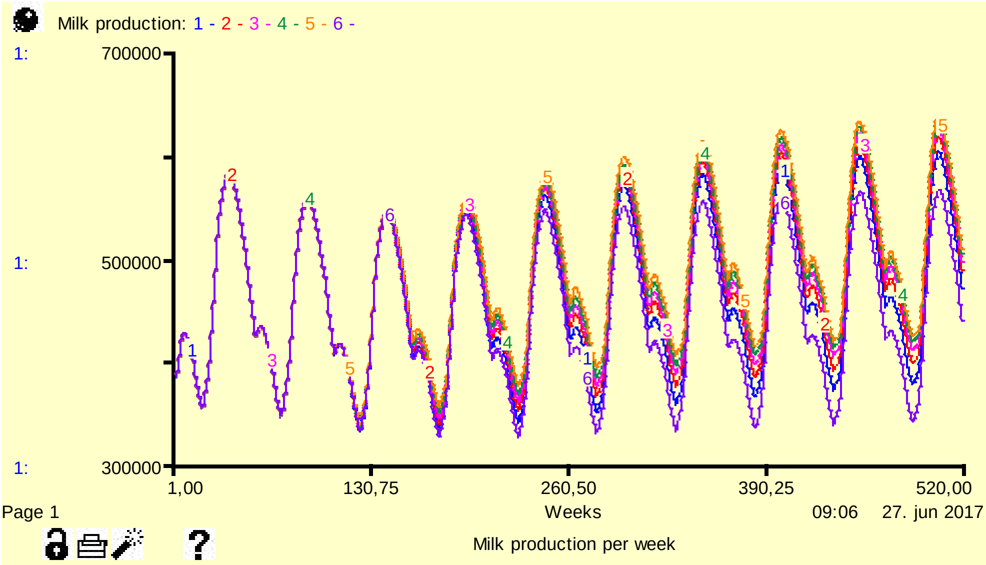


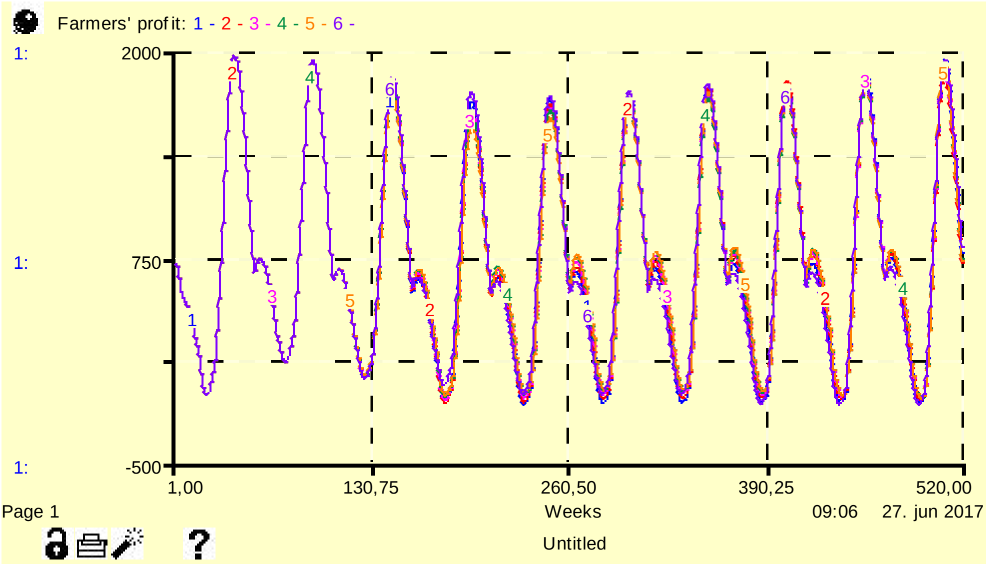
Scenario 2 investment sensitivity

The uncertainty of this parameter also necessitated a sensitivity analysis of different options for investment percentages. The sensitivity analysis reveals that the different percentage options have different effects on increasing the amount of land used for improved pasture. They also affect milk production, farmer profitability, and total cattle population differently. Based on the analysis, we decided to use 10% as the investment percentage since it both yields significant changes and is a realistic percentage in terms of farmer willingness to invest.

Simulation overview
1 = 0.05
2 = 0.1
3 = 0.15
4 = 0.2
5 = 0.25
6 = Baseline


Land used for improved pasture: 1 - 2 - 3 - 4 - 5 - 6 -
40000
20000
0
1,00
130,75
260,50
390,25
520,00
Page 2
Weeks
09:06 27. jun 2017
Land used for improved pastures

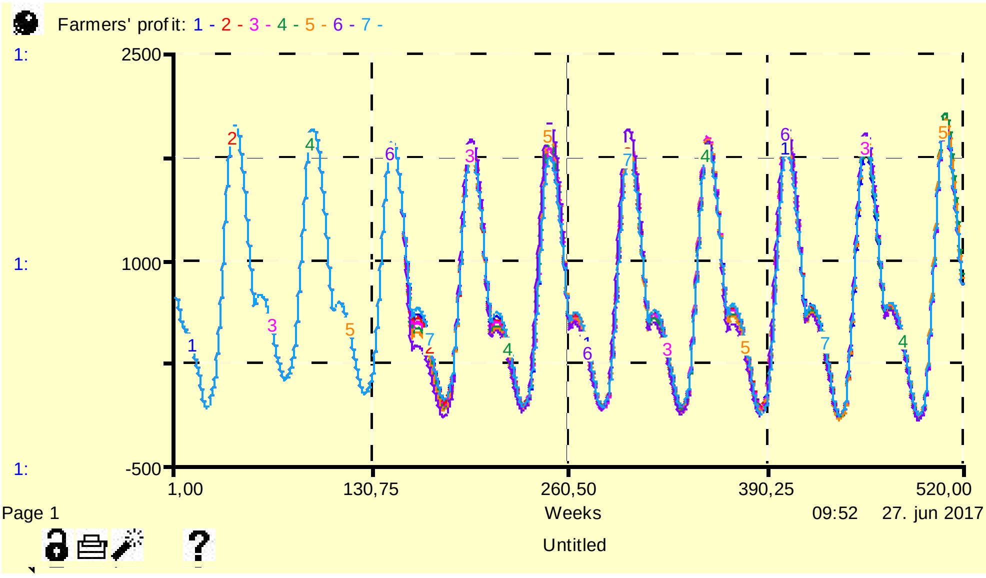

Milk production: 1 - 2 - 3 - 4 - 5 - 6 -
700000
500000
300000
1,00
130,75
260,50
390,25
520,00
Page 1
Weeks
09:06 27. jun 2017
Milk production per week

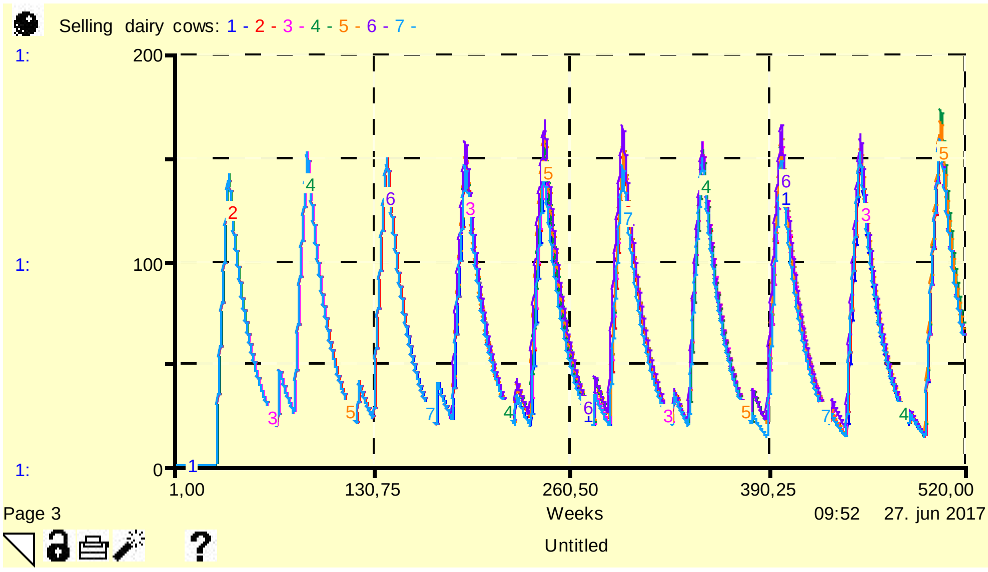

Farmers' profit: 1 - 2 - 3 - 4 - 5 - 6 -
2000
750
-500
1,00
130,75
260,50
390,25
520,00
Page 1
Weeks
09:06 27. jun 2017
Untitled

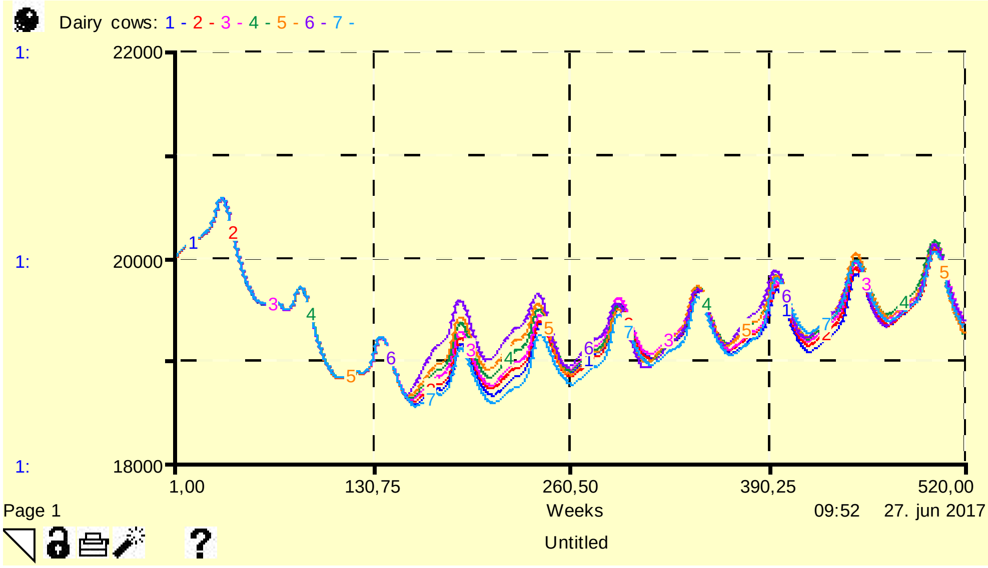
Scenario 3 investment sensitivity

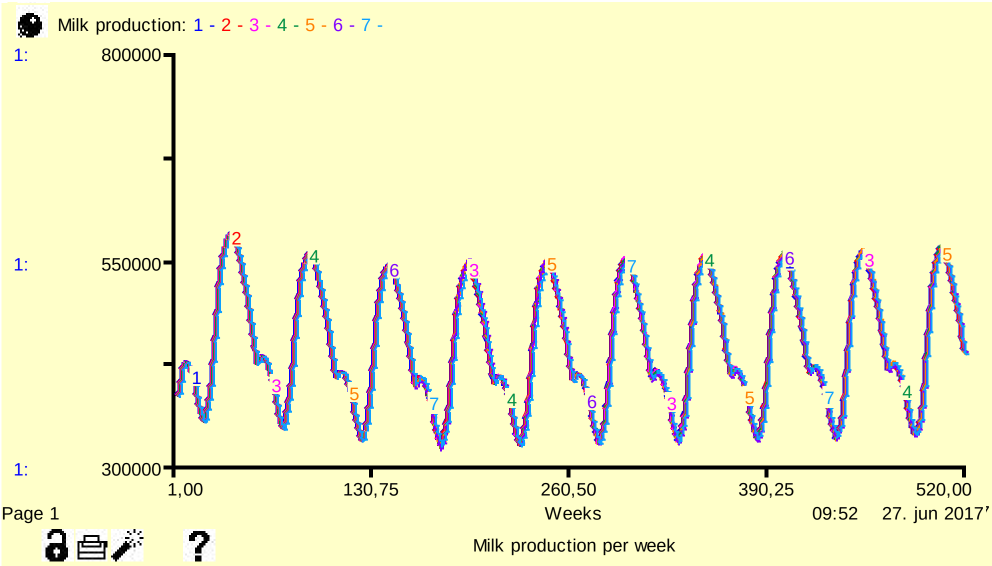
The sensitivity analysis illustrates that none of the investment percentages has any impact on the total cattle population or milk production. They only have a slight impact on farmer profit, which is only due to the purchase and sale of dairy cows within the same year. We therefore chose a relatively modest investment percentage of 10%.

Simulation overview
1 = 0.05
2 = 0.1
3 = 0.15
4 = 0.20
5 = 0.25
6 = 0.4
7 = Baseline





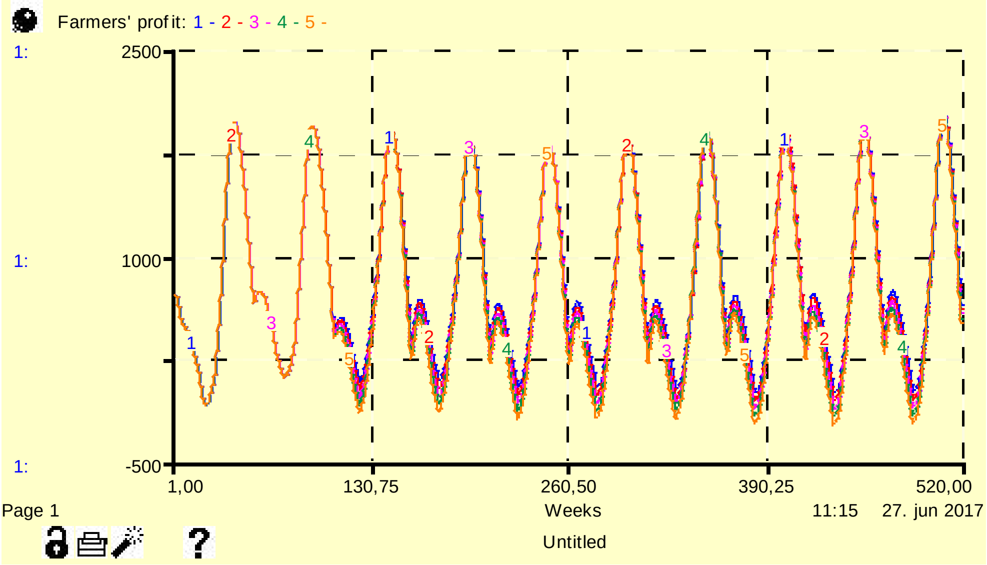


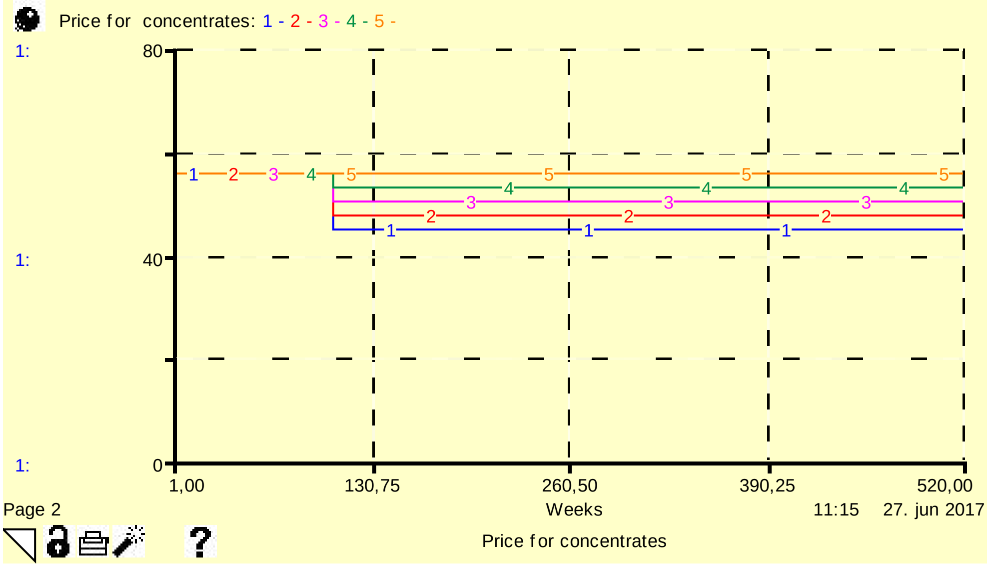


Appendix E: Sensitivity analysis of price for concentrate

The sensitivity analysis illustrates that only a 20% reduction of concentrates prices leads to a profitable milk production during the dry season when concentrates are used.

Percentage decrease in concentrate price:
1 = 20% (45 NIO/kg of protein)
2 = 15% (48 NIO/kg of protein)
3 = 10% (50 NIO/kg of protein)
4 = 5% (53 NIO/kg of protein)
5= 0% (56 NIO/kg of protein)


Farmers' profit: 1 - 2 - 3 - 4 - 5 -
1: 2500
1: 1000
1: -500
1,00
130,75
260,50
390,25
520,00
Page 1
Weeks
11:15 27. jun 2017
Untitled


Price for concentrates: 1 - 2 - 3 - 4 - 5 -
1: 80
1: 40
1: 0
1,00
130,75
260,50
390,25
520,00
Page 2
Weeks
11:15 27. jun 2017
Price for concentrates

Appendix F: Additional model graphs

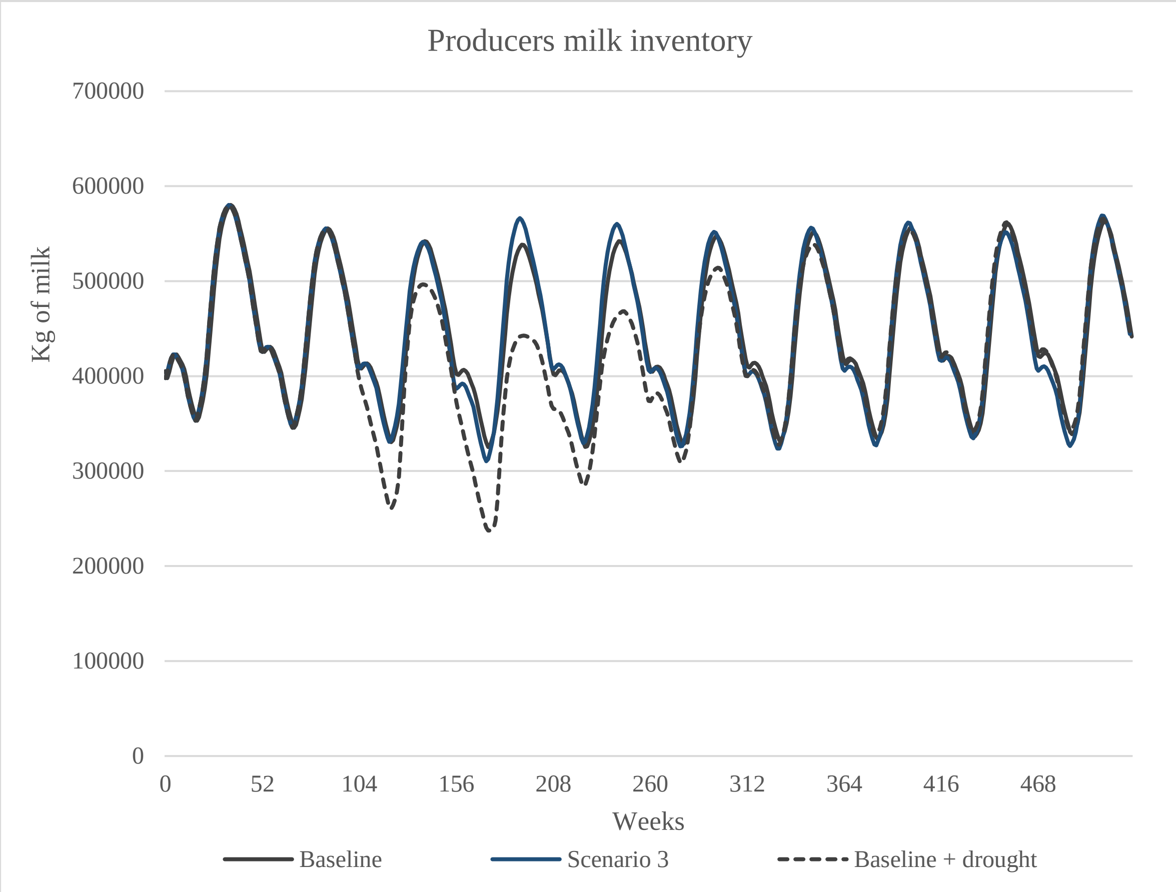


Figure F.1: Producers milk inventory in different scenarios. Source: Model simulations

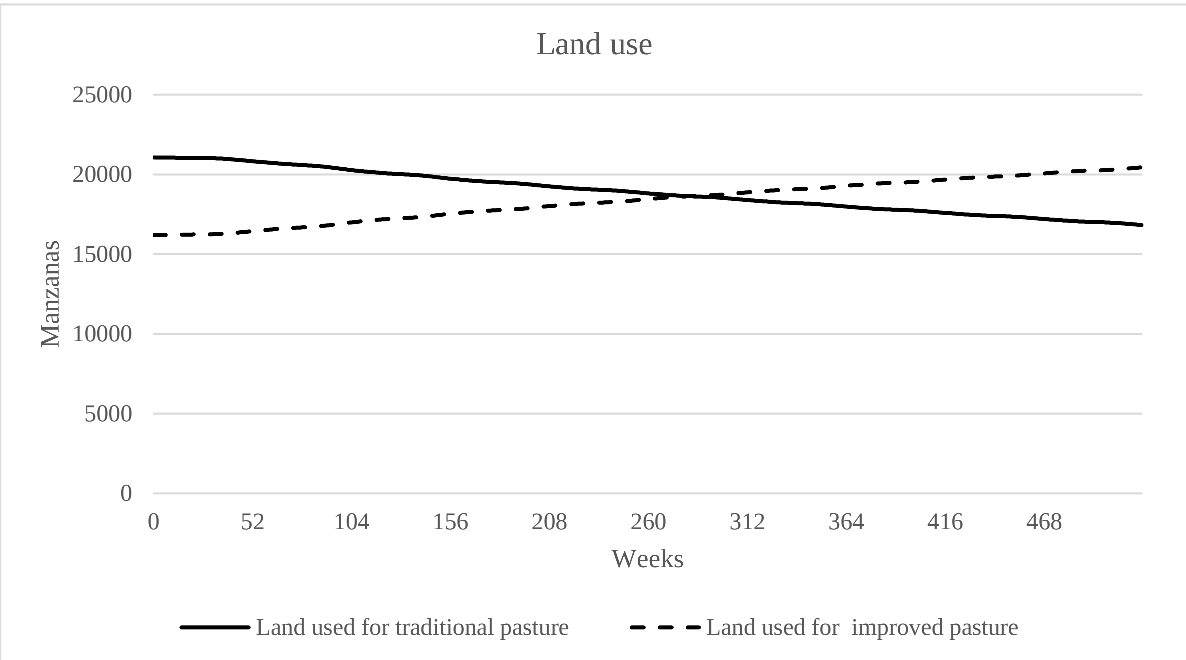


Figure F.2: Land use baseline scenario. Source: Model simulations

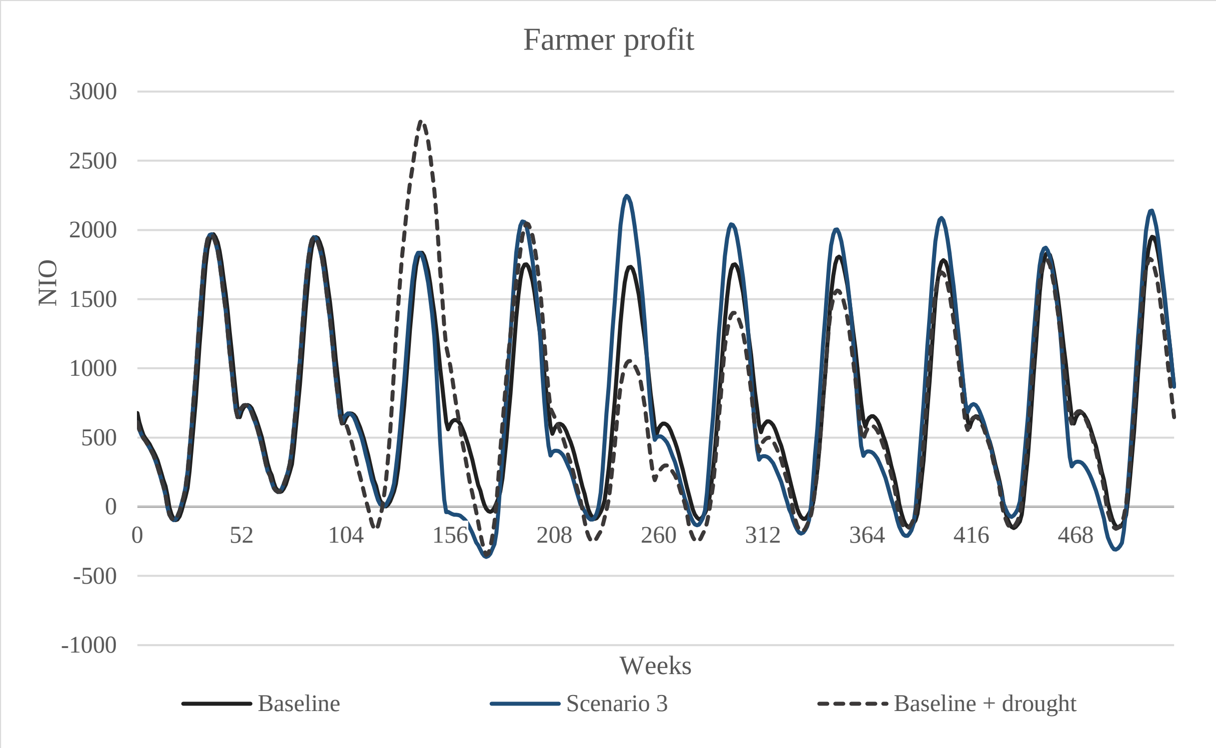


Figure F.3: Farmer profit in different scenarios. Source: Model simulations

APPENDICES

Appendix 1: Group model building scripts.

Source: Developed by the author

Script for GMB1

Time (min)	**Time used**	**Focus**
10 10 15	20	**1. Introduction** - Introduction of facilitators and focus of research. - Introduction of participants (make sure we have participants from each node) - Introduction of research (incl. expectations, plans, method, goals) Questions?
15	25	**2. What is the main goal/vision in the value chain for the actors in Matiguás?** - Plenary discussion. Reach consensus on the goal.
30	20	**3. What are the main problems with reaching the goal?** - Ask people to individually write down different problems. Round robin to hear the different ones. Write them in short on the board. Sort them.
10	10	**4. Prioritize problems** - Individually rank the 3 most important problems you would like to focus on. - Round robin to hear from each participant and identify the top ranked problems
	45	Lunch
20	25	**5. Brainstorm the causes of the highest ranking problem(s)** - Divide the group into 2 and ask them to write down causes to the problem
20	25	**6. Brainstorm the consequences of the chosen problem(s)** - In the same group write down consequences of the problem
10	10	**7. Make reference mode in plenary for the problem(s) chosen**
20	40	**8. In plenary add linkages between the causes, problem(s) and consequences.**
10	0	**9. General discussion** - Feedback on process, what do they think about the diagram, time for reflection
10	5	**10. Wrap-up** - What have we done today? What will happen next time? Decide dates for upcoming sessions.
Total 3hrs	Total 3hrs	Planned time: 11-15 including lunch Real time: 11.45 to 15.00 with lunch from 12.30 to 13.15

Script for GMB2

Time (min)	Time used	Focus
5	5	1. Introduction round of facilitators and participants and plan for the day 2. Recap from last time
10	9	3. **Show modified CLD in Vensim** (hand it out on paper too) - Talk about importance of CLDs in a modeling process - Explain the difference from the cause and consequence map - Ask if there are any important changes that needs to be made in the modified CLD. Use Vensim to make changes in real time.
15	16	4. **Presentation to introduce SD concept and language**
15	12	5. **Practical presentation of SD model in Stella** - Make and show a simple model based on cow production in Stella using Storytelling function - Run the model to show different scenarios.
15	14	6. **Present the conceptual model in Stella using storytelling function** - Verify main stocks and flows
15	26	7. **Add to the model** - Focus on the flow of milk and value chain structure
15		Break
30	25	8. **Add to the model in plenary** – changed to group work - Focusing on milk quality
30		9. **Add to the model in plenary** – changed to group work - Focus on feeds
15	12	10. **Add to the model in plenary** – changed to group presentations - What other aspects are important to add in the model?
10	22	11. **General discussion about the model** - What do they think about the model, learned anything so far? - What can/will they think about until next time? - Feedback on process, other reflections or questions
5	14	12. **Wrap-up** - Summarize what we have accomplished today - Say what will we do next time
Total: 3h	3hrs	Planned time: 9-12.30 and then lunch Real time: 10.20 to 13.10 + lunch

Script for GMB3

Time (min)	Time used	Focus
5	8	**1.** Introduction round of facilitators and participants and plan for the day **2.** Recap from last time
10	10	**3. Short repetition of SD language in groups** - Go into 3 groups that has been made beforehand - Give out paper with main concept explanation and go through stocks, flows, variable, connector, importance of measurability - Introduce feedbacks and delays
10	1h 25 min for 4. and 5.	**4. Introduce and verify the modified model in the groups** - In groups verify the structure on printouts (one group on each section: animal production, milk flow, feeds). Use cards/post its to add to the model and possibly use paper/flip charts if need to make many changes. - Make sure you add costs and potential revenue variables.
25		**5. Add numbers to the structure** - In the same groups, discuss the different numbers in the structure the group is focusing on. It might be necessary to add new variables here. - Each group write data in the model on post its (2 for each change) and further details in a note book provided
40 Total: 90	47 150	**6. Report back and discuss in plenary** - Each group present their paper by adding their changes to the main print out on the board. Use the second post it for the main print out on the board. Present data, but not in detail - Each group has 10min for presentation including discussion in plenary. - Verify the entire model before moving on
15	35	Break
20	55	**7. Add to the model** (Investment, adoption, profitability) - Go into the groups again. Each group focus on different topics (1) farm-level profitability; (2) drivers of innovation; (3) investment dynamics and capacity, and cost and revenues from feeds
40	16	**8. Report back from group work and discuss in plenary** - Present additions on big paper. Each group have 10min including discussion in plenary. - Verify the Stella version before moving on
10	0	**9. General discussion about the model** - What do they think about the model, learned anything so far? - What can/will they think about until next time, - Feedback on process, other reflections or questions
5 Total: 75min	6 77	**10. Wrap-up** - Summarize what we have accomplished today - Say what will we do next time
Total: 3h		Lunch together in the end Real time: 10.15 to 14.45 with lunch from 12.50

Script for GMB4

Time (min)	**Time used**	**Focus**
5	5	**1.** Introduction round of facilitators and participants and plan for the day - Goal for today is to get specific data needed and verify structure **2.** Recap from last time **3.** Reminder on what the goal is for this research
90 Total: 1h35	90	**4. Group work to verify and discuss data needed** - Group 1: animal and feeds structure - Group 2: milk flow and adoption and investment structure - Go through the structure to see if the group agrees to it. - Discuss the questions prepared for each structure - Prepare who is going to present your discussion and what to present
15	30	**Break**
40		**5. Report back and discuss in plenary to verify data** - Use the printed models provided to present - 20min per group including plenary discussion
20	40	**6. General discussion about the model, model process and evaluation** - Go through the 12 problems from GMB1 – which ones have been covered in the model? - Have we focused on the goal we set? - What will I do from now on - What do they think about the model, learned anything so far? - Feedback on process, other reflections or questions. Go around the table and ask.
5	5	**7. Wrap-up** - Inform them about the final meeting for delivery of preliminary results
Total: 2h40		Planned time: 9.30-14.00 Real time; 10.15 to 14.45

Script for GMB5

Time (min)	**Time used**	**Focus**
15	20	**1. Introduction of work done between last time and now and the goal for today**
30-45	55	**2. Show the model and some model simulations** - Show the conceptual model and go through it quickly (use iThink storytelling) - Go through different simulations based on different scenarios - Verify overall runs (milk production, land use, farmers profit)
10	0	Small coffee break when going into groups (during group work)
60-90	1h 10	**3. Group work to verify structure and data in each structure** - Group 1 herd dynamics and milk sales and processing - Group 2 feed dynamics and costs and revenues - Use large printed models, have data printed on papers and use post its to mark changes - Also do real time runs with changes in the groups separate (one group did this)
30	50	**Lunch**
45	45	**4. Plenary discussion on interventions and scenarios** - How can we improve feeding systems/milk production (1. Concentrate, 2. Improved pasture, 3. Better animals) - What other interventions/scenarios are important to consider
20	20	**5. Discussion on how to use the model** - Who can use the model and how, make a plan - What can Helene and/or CIAT do to ensure availability/use
20	10	**6. Feedback on model process and evaluation** - What have we learned from this modeling process (both from the process itself and the preliminary results from model scenarios)? - What worked? - What did not work? - Comments, questions, suggestions?
10	10	**7. Individual evaluation** **-** Questionnaire focusing on the process and learning
Total: 4h40		Planned time: 9.00- 15.00 Real time: 10.15-14.50