Universität für Bodenkultur Wien
University of Natural Resources and Life Sciences, Vienna

Master Thesis

Surveyed and modelled income effects of smallholder dairy farming in Kakamega County, Kenya

Submitted by

Monika STRADNER, BSc

in the framework of the Master programme

Agrar- und Ernährungswirtschaft

in partial fulfilment of the requirements for the academic degree

Diplom-Ingenieurin

Vienna, February 2022

Supervisor:

Univ.Prof. Dipl.-Ing. Dr. Erwin Schmid
Institute for Sustainable Economic Development
Department of Economics and Social Sciences

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Affidavit

I hereby declare that I have authored this master thesis independently, and that I have not used any assistance other than that which is permitted. The work contained herein is my own except where explicitly stated otherwise. All ideas taken in wording or in basic content from unpublished sources or from published literature are duly identified and cited, and the precise references included.

I further declare that this master thesis has not been submitted, in whole or in part, in the same or a similar form, to any other educational institution as part of the requirements for an academic degree.

I hereby confirm that I am familiar with the standards of Scientific Integrity and with the guidelines of Good Scientific Practice, and that this work fully complies with these standards and guidelines.

Vienna, 13.02.2022 Monika STRADNER (manu propria)

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Abstract

While smallholder farmers in Kenya provide a considerable amount of food for the local market, many of them are affected by poverty. Productivity increases in agriculture are being regarded as an important measure to reduce poverty in Sub-Saharan Africa. Smallholder farmers in Kenya's West need to find alternative income sources due to deteriorated conditions for sugarcane farming. Dairy farming is being promoted as it provides food for the household and generates additional income. In 30 interviews with smallholder dairy farmers in Kakamega County, details about the farmers, their situation, and characteristics about their farms have been collected to gain comprehensive insights. The Master thesis' aim is to position Kenyan smallholders in a bigger frame regarding relationships of agricultural productivity, poverty reduction, and economic development in Sub-Saharan Africa. Furthermore, a dairy farm model analysis is conducted using Linear Programming (LP) in order to support decision making of dairy farmers in Kenya. The interviewed farmers mention milk sales as an important income source as well as manure management to improve soil fertility and higher crop yields. Pests and drought have been stated as challenging factors. The interviewed farmers also mentioned their plans with respect to dairy production in order to further improve the household's income situation. According to the model analysis, the annual income of a typical smallholder dairy farm in Kakamega County amounted to 48,950 KES in 2018. Three scenarios (SC1: increasing the number of dairy cows, SC2: intensifying the feeding ration, SC3: farmer cooperation) to increase the income have been analyzed by applying the LP on a typical dairy farm. According to the model results, intensified feeding could increase the farm income by up to 134%. Support measures are necessary to increase farm productivity such as education programs or subsidizing inputs such as concentrate feeds.

Kurzfassung

Während kenianische Kleinbauern für einen Großteil der lokalen Nahrungsmittelproduktion sorgen, sind viele von ihnen von Armut betroffen. Produktivitätssteigerungen in der Landwirtschaft werden als wichtiges Mittel zur Armutsbekämpfung angesehen. Aufgrund von veränderten Bedingungen im Zuckerrohr-Sektor müssen sich Kleinbauern in Westkenia an alternativen Betriebszweigen orientieren. Milchwirtschaft versorgt den Haushalt mit Nahrung und ist zugleich eine gute Einnahmequelle. In 30 Interviews mit Kleinbäuerinnen und -bauern im Kakamega County konnten Betriebsdaten gesammelt und ein Einblick in ihre Situationen erhalten werden. Der Zusammenhang von wirtschaftlicher Entwicklung, Armutsbekämpfung und landwirtschaftlicher Produktivität in Ländern südlich der Sahara stellt den Rahmen dieser Arbeit dar. Weiters wird ein Überblick über die Milchwirtschaft in Kenia gegeben. Mit einem linearen Optimierungsmodell für einen typischen kleinbäuerlichen Milchviehbetrieb werden drei Strategien zur Einkommensgenerierung untersucht. Die befragten Bäuerinnen und Bauern sehen den Verkauf von Milch als wichtige Einnahmequelle und berichten darüber hinaus von verbesserter Bodenfruchtbarkeit und höheren Erträgen. Schädlinge und Trockenheit werden als Herausforderungen genannt. Mit den erhobenen Daten wurde ein typischer, kleinbäuerlicher Milchviehbetrieb in Kakamega County im Jahr 2018 dargestellt. Das Jahreseinkommen dieses Betriebes war 48.950 KES. Drei Szenarien (SC1: gesteigerte Anzahl von Milchkühen, SC2: intensivierte Fütterung, SC3: gemeinschaftliche Produktion) zur Einkommenssteigerung durch gesteigerte Milchproduktion wurden entwickelt und analysiert. Die Modellanalyse zeigt, dass das SC2 zu einer Einkommenssteigerung von bis zu 134% führen kann. Bildungsmaßnahmen zum Thema Fütterung der Milchkühe und finanzielle Unterstützung beim Zukauf von Kraftfutter könnten die Produktivität auf diesen Betrieben und in weiterer Folge das Einkommen der Bäuerinnen und Bauern steigern.

1. Introduction

1.1 Eradicating poverty by supporting smallholder farmers

More than half of the world's extreme poor can be found in Sub-Saharan Africa (SSA). Around 40% of the population there were living below the so-called poverty line in 2018 (Schoch & Lakner, 2020, s.p.). This value is defined by the poverty headcount ratio, meaning that a person lives on less than USD 1.90 (indexed with the purchasing power parity of 2011) per day (WBG, 2021, s.p.). In 2015, the United Nations (UN) defined their Sustainable Development Goals (SDGs) to be reached by all countries by 2030. These 17 goals unite economic, social, and ecological indicators. The headline of goal 1 is: "End poverty in all its forms everywhere". It includes a wide range of subdivided targets such as healthcare access, equal and human rights, food security, the impact of climate-related events and other economic, social, or environmental shocks. Besides the focus on earnings and wages, the supply of products and services for people living on low level incomes is being targeted as well (UN, 2021a, s.p.). While it is important for poverty eradication to consider more than only the income aspect, a higher income for individual households can be vital to alleviate poverty. Closely linked to goal 1 is goal 2 which deals with hunger, food security and sustainable agriculture. The doubling of agricultural productivity and higher incomes for small-scale food producers have been set as targets to reach this goal and stop hunger in our world (UN, 2021b, s.p.).

Several international organizations suggest, based on economic transformation theories, supporting smallholder farmers as a key factor for poverty eradication in Africa (ACET, 2017, pp.49; Fan et al., 2013, pp.3; FAO, 2016, p.14; Timmer, 2014, pp.4). In contrast, Collier and Dercon (2014) assert that what can be observed in SSA economies today can not be considered yet an economic transformation: many poor smallholders there are still responsible for the bulk of the agricultural output while facing low yields, limited commercialization, and low productivity growth rates (Collier & Dercon, 2014, p.92). An increased agricultural productivity growth rate is the crucial factor for an economic transformation process, which has been highlighted by various international economists (e.g. Timmer, 1988, pp.277; Mellor, 2017, p.32) and will be further discussed consistently throughout this thesis, especially in *section 2.2.1*.

The African Transformation Report (ACET) concludes that agricultural transformation consists of a combination of modernization, increased productivity, overall diversification as well as specialization on individual farms, and scientific knowledge-based farms that are linked to each other and further economic sectors. According to this report, agriculture has the potential to lead the path to industrialization, just as the Green Revolution (GR) did in many countries, especially in Asia (ACET, 2017, pp.1-3). Since 1960, some parts of the world were able to triple their average cereal yields while yields in SSA only increased to a small extent. Hazell (2009) sums up various reasons that explain this fact, for instance too little investments in infrastructure. Smallholder farmers frequently struggle with high prices and limited input availability, as well as competition with low-cost food imports from countries that subsidize their agricultural products. The success of a GR strategy for SSA depends on governments that support the agricultural sector with a long-term objective and the awareness for mistakes that happened during the first GR, such as environmental damages caused by inappropriate fertilizer use or irrigation practices (Hazell, 2009, pp.22-24).

Given the claims stated above, productivity increases on smallholder farms in SSA shall have a positive impact on agricultural production and food security, structural transformation, and the farmers' incomes. The concern of the present thesis is to review these potential effects with a farm model application in Kakamega County, western Kenya. On-site research has been conducted in Kenya in the beginning of the year 2019 to be able to receive a comprehensive view of the farmers and their situation, and to procure the economic household and farming data needed for the analysis. The resulting outcomes are being presented in this thesis.

1.2 Problem statement and research questions

In its "Vision 2030", the Kenyan government states that it wants to become a newly industrializing, middle-income country by 2030 (GoK, 2007, p.1). One important backbone of the country's economy and contributor to Kenya's Gross Domestic Product (GDP) is agriculture. Around 70% of the rural population is employed in agriculture, 63% of all food produced in Kenya comes from smallholder farmers. While Kenya's dairy sector is one of the most developed in SSA, about 70% of the milk originates from roughly one million smallholder farmers owning one to five dairy cows (FAO, 2011, p.2). The Vision 2030's goals for the agricultural sector are increasing the agricultural value, raising incomes, and adding value to products before they reach the market. These goals could be achieved by innovative, commercially oriented, modern agriculture, higher yields, and smallholder specialization. Therefore, it is planned to support agricultural households in increasing productivity and achieving better market access for their products (GoK, 2007, p.13).

Smallholder farmers in Kakamega County in Kenya's west used to produce sugarcane for the local sugar refinery. Due to changed circumstances in the industry, the company faced financial problems and the farmers started to look for appropriate income alternatives. Instead of relying on a single cash crop, the Kakamega County government encourages diversification in dairy, tea, and poultry farming (Otenyo, 2019, s.p.). It wants to increase the quantity of milk being produced by local farmers to ensure the supply for running a dairy processing plant in the region (CGK, 2019, s.p.). Non-governmental organizations (NGOs) support the idea of smallholders engaging in dairy production, as it has the potential to increase farmers' incomes, to ensure food security and to open new opportunities (Boru & Ambunda, 2018, s.p.). The Kakamega County Dairy Development Corporation (KDDC) was established by the county government to support dairy farmers with certain assets, such as setting up a milk processing plant and dairy training facilities, promoting dairy cooperatives, and initiating projects providing farmers with dairy cows (CGK, 2018b, pp.4). An overview of the study region is being presented in *section 3.1*.

The aim of this thesis is to explore the income effects of increased productivity in dairy farming on a typical smallholder farm in Kakamega County. Therefore, the collected farming activities are being analyzed to develop a model for a typical dairy farm in the region. Furthermore, details about the farm household, recent challenges, chances and plans of the farmers are analyzed to provide insights into their living and working conditions. The research questions are:

- *What are typical farming activities and their income generating potential for smallholder farmers in Kakamega County?*
- *What are the personal issues and farming strategies of smallholder farmers in the study region?*

Furthermore, three strategies are analyzed by means of linear programming in order to increase the labor productivity by producing a higher quantity of milk and the respective effects on the farmer's income. Therefore, following research question is analyzed:

- *What are the effects of different milk production intensification strategies on the farming income of a typical smallholder farm in Kakamega County?*

An increased labor productivity can be reached by increasing on-farm yields, farm sizes, and/or reducing labor time (FAO, 2016, p.14). The implementation of the three scenarios is being analyzed with a farm Linear Programming (LP) model (*see section 4.4*). The database is used to develop the three scenarios. The main characteristics of the scenarios are:

- Increasing the amount of dairy cows
- Intensifying the feeding ration
- Establishing a farmer cooperation

This thesis is structured as follows: subsequently, chapter 1 closes with terminology. Chapter 2 introduces background knowledge. In chapter 3, material and methods are explicated and chapter 4 presents the obtained results. A discussion of these results and applied methods as well as final conclusions are given in chapters 5 and 6.

1.3 Terminology

Central terms for this thesis are being defined as follows:

1.3.1 Who is a smallholder farmer?

The terms smallholder farm, small-scale agriculture, family farm, or subsistence farm are often used to describe the same thing (Brüntrup & Heidhues, 2002, pp.1-3). Khalil et al. (2017) summarized common definitions of small-scale food producers and noted that the context determines which farmers would be identified as smallholders. They specified four characteristics to classify smallholder farms:

- Production factor endowment (degree of family labor or farm size)
- Farm management type (farm run by a family or as a business)
- Market orientation (level of subsistence and market participation)
- Economic size of the farm (production value)

The distinction by area, meaning a farm size smaller than two hectares characterizing a smallholder farm, is common and often used. Even though in certain countries larger farms can still be smallholder farms (Khalil et al., 2017, pp.11-14). Most smallholder farmers produce food primarily for their own family and participate in markets where they sell surpluses, therefore the level of subsistence is variable. Off-farm incomes of household members have an influence on the economic situation of the farm and could be taken as a demarcation indicator (Brüntrup & Heidhues, 2002, pp.1-3). Smallholder farmers play an important role in many developing countries, as they produce about two thirds of the countries' food consumptions (Rapsomanikis, 2015, p.8). An important indicator is the gap between technical potential yields, supposing optimal conditions, and the effectively achieved outputs. Rapsomanikis (2015) reports a difference of up to 76% in SSA due to improper input use and a lack of technological adoption, as smallholder farmers often face limited market and technological access (Rapsomanikis, 2015, p.10). As farm sizes are small the labor force primarily consists of the family. Family members tend to be more motivated, productive, need less supervision, and spend more time working. Rapsomanikis (2015) argues that family labor is even being over-used, as more hours are spent working than would be consistent with profit-maximization. He relates to the small returns to labor in agriculture and limited opportunities for well-paid labor in rural areas (Rapsomanikis, 2015, pp.14). Smallholders owning livestock have an opportunity to produce protein food and increase the fertility of their fields by manure application. While smaller animals like chicken are easier to handle, a dairy cow has higher maintenance costs and needs a more skilled farmer to manage dairy production (Rapsomanikis, 2015, p.20). Overall, a smallholder's production volume is small, and certification and quality requirements make market participation more difficult. A strategy to strengthen the individual farmers' market position is to establish a farmer cooperation to bundle small production quantities, organize marketing together and benefit from economies of scale, like large producers do (Rapsomanikis, 2015, p.33).

Mellor (2017) introduces a different approach to classify smallholder farmers. He is arguing that scientific literature, foreign aid and even governments primarily focus on smallholder farmers, supposing that all of them are poor and unable to take financial risks. As smallholders account for the lion's share of agricultural production, a substantial fraction of them does take part in markets and remarkably contributes to poverty reduction. Small commercial farmers are "not poor and spend a substantial portion of their incremental income from farming on labor-intensive non-tradable goods and services from the large, rural, non-farm sector" (Mellor, 2017, p.1). They can sell at least one third of their produce and are therefore able to consume above the poverty line. Smallholders who are mainly producing at the subsistence level and whose income is at or below the poverty line are in contrast part of the rural non-farm sector, according to Mellor's definition. Small commercial farmers have the capacity to invest capital to raise their farm income and demand non-food items locally, goods and services as for example house improvements, furniture, or school tutoring. Their consumption has the potential to lift the rural poor out of poverty, as it triggers an employment and income increase in the rural non-farm sector. Thus, small commercial farmers in low-income countries have an important impact on GDP growth and economic transformation (Mellor, 2017, pp.1).

In this thesis, the specification by farm acreage less than two hectares (respectively five acres) is being utilized to classify a smallholder farmer. The definition by farm size is a straightforward and practicable way, a statement about subsistence level or production volume would require more detailed information about the farms in advance.

1.3.2 Labor productivity

“Labor productivity represents the total volume of output (measured in terms of GDP) produced per unit of labor (measured in terms of the number of employed persons) during a given time reference period” (ILO, 2020, p.1). The indicator helps to understand growth rates and labor market situations in countries or specific sectors. A positive economic performance is being represented by increased labor productivity as employment in jobs with higher productivity rises or work in general is becoming more efficient (for instance through better organization, improved production facilities, or higher-educated employees). Factors like physical and institutional infrastructure as well as human capital and technology have an influence on labor productivity, therefore policies affecting these factors can support economic growth and subsequently the population’s living standard (ILO, 2020, pp.1).

The productivity increases mentioned throughout this thesis are related to on-farm labor productivity. The formula above is being adapted in this thesis, the volume of output is represented by the farming income and being divided by the utilized labor hours.

2. Case study and methodological background knowledge

The following part gives an overview and provides details on the topic's various aspects. It includes definitions, introduces dairy farming in Kenya, explains the context of agricultural productivity for economic transformation, and presents LP modeling to support farm decision-making.

2.1 Dairy farming in Kenya

Kenya is a lower middle-income country with a rising GDP, annually growing at a rate of about six percent (KNBS, 2018a, p.71). To reach the goals as planned in Vision 2030 and to advance towards a middle-income economy, agriculture has been identified as one of four focus areas in an economic report by Awiti et al. (2018). Public spending in the sector should increase, as it was less than two percent of the total expenditures in 2016/17. Especially investments in public goods, such as rural roads, electricity, irrigation, and extension services would, due to the large number of people working in the agricultural sector, have a positive impact on poverty reduction and economic growth. Another topic of rising importance is the reaction to climate change occurrences with measures such as drought resistant varieties and improved soil and water management (Awiti et al., 2018, p.35).

Livestock keeping and the subsequent manure use is a strategy for smallholders to increase soil fertility. Dairy farming reinforces the family's food security by adding a protein source and enables additional income. In Kenya, the average milk consumption per capita is 120 liters per year (MoALF, 2013, p.4), while urban and high-income-households have a higher consumption than rural, low-income-households do. Due to population growth and increasing urban population as well as incomes, the demand for dairy products is likely to increase. Meeting quality and production standards is an important precondition for taking part in the international milk market (MoALF, 2013, p.16).

2.1.1 Historical insight and sector development

During the colonial era starting in 1900 dairy farming in Kenya was large-scale, export-oriented and driven by European settlers. After independence in 1963, the government focused on attracting natives to engage in small-scale dairy farming. Since market liberalization in the 1990s, many of the achievements disappeared as farmers could not afford certain services anymore. Artificial insemination (AI) is an example – it was being promoted and financed by the government and widely used by the farmers, but almost disappeared after being taken care off by the private sector. After a volatile period going with changing policies, corruption, and the fall of the state-run creamery, today the focus lies on economic revival and learning from past mistakes (FAO, 2011, p.4; MoALF, 2013, p.2). More than 75% of the marketed milk in Kenya is being sold at the informal market, most of it sold as raw milk. After market liberalization the already existing milk collection and bulking system in the formal market collapsed (FAO, 2011, p.13). Today, Kenyan consumers prefer raw milk as it is cheaper, widely accessible, they like the taste and can buy variable quantities (FAO, 2011, p.14). The prices for farmers tend to be higher than in the formal market and they receive their payments immediately, therefore many farmers prefer it. From the government's perspective, the formal milk market would offer numerous advantages: value addition, employment creation, observation of quality standards, enhanced marketing, and export potential (FAO, 2011, p.25; Odero-Waitituh, 2017, s.p.). As Kenyan consumers are used to raw milk and boil it prior to consumption, the infection risks from bacterial health hazards are low (FAO, 2011, p.19). All these market conditions and consumer preferences might be considered when fostering on intensification and the creation of a dairy processing infrastructure.

About 70% of the milk on the Kenyan market originates from over one million smallholder farmers rearing up to five dairy cows (FAO, 2011, p.2). Linked to the preceding conditions, the Kenyan dairy industry faces several challenges: insufficient feedstuffs, poor animal health, unavailability of quality replacement stock, low technology adoption, and expensive farm inputs. Only a small number of farmers create value added products e.g. from processing and direct marketing. Zero grazing is being promoted as optimum production system for smallholders to reach a commercialized level of dairy farming with increased productivity, manure management opportunities and a feeding strategy (MoALF, 2017, p.9). Former land sub-division into small and less economic field sizes in combination with high population density causes a lack of available pastures. Farmers are forced to graze their animals in inappropriate areas and are not able to provide sufficient nutritive feedstuffs (MoALF, 2013, p.30; Kibiego et al., 2015, s.p.; Njarui et al., 2016, s.p.). The conditions in less populated areas would enable less intensive dairy production, meaning either combining grazing during the day and stall feeding at night or purely paddock grazing (Odero-Waitituh, 2017, s.p.). In densely populated regions farmers dealing with limited land sizes need to adopt to zero grazing and develop feeding strategies to economically provide adequate, sufficient, and nutritious feedstuffs for their dairy animals.

2.1.2 Practical aspects of zero grazing

As already discussed, the available resources on the farm determine the dairy production system. Lukuyu et al. (2012) summarized facts about rearing dairy cattle in East Africa in their report from the East Africa Dairy Development Project. Where grazing land is not available, zero grazing units are the only option. This system offers several advantages for farmers: cows do not burn energy walking around and searching for feed; diseases that would be spread via communal grazing areas can be avoided; even farmers who do not own grazing land can produce milk and generate an income. Another positive aspect is the simple collection of manure, which can be used as organic fertilizer to improve soil fertility (Lukuyu et al., 2012, pp.13). Furthermore, it is easier to adopt the feeding intensity according to the level of milk production. As the animals are physically closer to the people who work with them, disease and parasite management could be facilitated and the occurrence of infectious and tick-borne diseases is lower than in grazing systems (Njarui et al., 2016, s.p.). Disadvantages of zero grazing are the increased labor use and the more difficult heat detection. As the cow stays inside the unit, feed and water must be fetched, prepared, and given to the animal. Extensive production demands large areas of available land while being cheaper and, compared to zero grazing, less labor intensive. Difficult aspects are manure collection and the pasture quality, as natural grasses often do not fulfill quality requirements and need to be improved. A semi-intensive production system would represent a mixture of the above-mentioned, but land sub-division and population increase favor the intensive zero grazing system. Roadside grazing or tethering do not meet the animals' needs and are therefore not being promoted. The factor that is limiting milk yields in East Africa most is the forage quality. For that reason, efficient pasture management (weed control, fertility management, and fodder conservation) is crucial for good-quality pasture and subsequently high milk yields (Lukuyu et al., 2012, pp.13). Common fodder crops in East Africa are Napier grass (*Pennisetum purpureum*), sweet potato vines (*Ipomea batatas*), oats (*Avena sativa*) and fodder sorghums (*Sorghum sudanese*). They have a high forage yield and can be fed either green or in a conserved form during dry periods. Especially Napier grass is very common among smallholder farmers in East Africa. It can be planted solitary or intercropped. Fertilization is recommended, the grass can be first harvested after reaching a height of one meter and is being chopped before feeding. In Kenya, the "Tumbukiza method" for planting is well established. The Kiswahili word means 'placing in a hole', as plant cuttings or root splits are being planted in well-manured holes. This method increases land productivity as it demands less land per dairy cow. It leads to higher yields on smaller pieces of land, faster regrowth, and feed availability during the dry season. In addition, forage legumes with their high crude protein levels are suitable as protein supplement for dairy cows and simultaneously improve soil fertility through nitrogen fixation. Common legumes among dairy farmers in the region are *Desmodium spp.*, lucerne (*Medicago spp.*) and *Dolichos lablab*. Another cheap protein source on smallholder farms are fodder trees, such as *Calliandra calothyrsus*, *Leucaena diversifolia* and *Leucaena trichandra* or *Sesbania sesban*. Leaves, pods, and young twigs are being used and remain available during dry seasons (Lukuyu et al., 2012, pp.21). Farmers would, depending on their individual resource endowments, additionally use crop residues from maize and bananas or other weeds for daily cut-and-carry feeding. The addition of concentrate feeds, such as dairy meal or maize bran, is an important factor influencing the milk yield (Njarui et al., 2011, s.p.). As forage production is rain fed, the availability and subsequently milk production fluctuate with seasons. Forage conservation is essential to supply a dairy cow with quality feed even in dry weather periods, therefore knowledge about hay- and silage-making is highly valuable for the farmers (MoALF, 2013, pp.8).

Local zebu cattle are being replaced and cross-bred with European cattle, mostly Friesian and Ayrshire, Guernsey and Jersey breeds are less common (Bebe et al., 2002, p.117). AI and improved breeds are available but depend on financial endowments of the farm (Odero-Waitituh, 2017, s.p.). Mugambi et al. (2015) argue, that smallholder farmers often do not reach the milk yields that would be possible due to their dairy animals' genetic potential. More efficient farm management and providing adequate feedstuffs, concentrates and mineral supplements could increase the achieved yields (Mugambi et al., 2015, s.p.). Compared to milk yields in extensive production, the obtained ones in zero grazing systems are significantly higher. The revenues exceed the production costs and farmers have a profitable income source (Mburu et al., 2007, s.p.). Kibiego et al. (2015) highlight, that if milk yields remained low due to management mistakes, free grazing would be better than zero grazing, as it is related to lower input and labor costs. The profitability of intensification is given in a defined range if input investments are reflected by increased milk yields and functioning markets to sell these (Kibiego et al., 2015, s.p.). This thought relates to economic efficiency, based on the law of diminishing returns. It treats the relationship of an additional unit of input and its effect on the output, originally proven with plant fertilization and growth experiments, later for animal production as well (McNall, 1933, pp.167-170). Milk yields can increase through a more intensified feeding strategy, after reaching a certain point an additional investment in intensification does not cause the expected return. The investment (marginal costs) and its expected economic lifetime need to be assessed in relation to the additionally produced yield (marginal value), taking future price developments into account. Widespread knowledge about animal and farm management is crucial for the smallholder dairy farmers who are intensifying their production. Extension services and market access improvements can have a positive impact on strengthening their competitiveness by increasing economic efficiency (Kibiego et al., 2015, s.p.).

Literature about dairy farming in the developing world puts the focus on intensification and productivity increases. Kenya faces agricultural land constraints for dairy production while farmers are being encouraged to increase milk yields by adopting zero grazing. In the second half of the last century, the introduction and immense growth of industrial livestock farming globally raised the societal question about animal husbandry conditions. The Brambell Report was released in 1965 in the United Kingdom and contained the declaration of five freedoms for farm animals. These were the foundation for animal welfare analysis in livestock industry and have been further developed in the following decades. Today, they contain being free from hunger, thirst, discomfort, pain, injury, disease, fear, distress, as well as being able to express normal behavior (FAWC, 2009, s.p.). Contrary to industrialized countries, most of the dairy farmers in Kenya are smallholders with only a few cows, their stalls often do not have a concrete floor and naturally provide conditions as sunlight and fresh air. Without having access to pasture the question arises, if zero grazing units can provide comfortable resting areas, and the dairy cows can act out their normal behavior. Aleri et al. (2012) did a study about the welfare of zero grazed dairy cattle on smallholder farms close to Nairobi and the results showed poor welfare conditions. The housing facilities were implemented in different styles, in most cases they posed a risk of injuries to the animals and were too small. Combined with suboptimal feeding and hygiene, poor body conditions and reduced milk production could be observed. The awareness of animal welfare matters was not present among the visited farmers. This highlights the need for training and education in that topic, especially about the relationship between good animal welfare and productivity (Aleri et al., 2012, s.p.). Eadie (2012) identifies a high potential for improving animal welfare for livestock in developing countries. Financial constraints do not favor the conditions for balancing animal and human welfare in regions where human survival is not certain. As governments are occupied with poverty reduction and economic growth, animal husbandry laws are not of utmost importance. But animal welfare is closely linked to animal health. A certain interest of meeting animal welfare’s requirements should be given as a rapid growth of industrial farming has the potential for spreading diseases in the population. Livestock is an important and valuable resource, and human moral tells us to prevent these beings from suffering (Eadie, 2012, pp.27).

Summing up - dairy production in Kenya has a certain history that is affecting market conditions until today. Establishing a well-performing, modern dairy sector, meeting local needs, managing available resources efficiently, also considering animal welfare, can improve the livelihoods of many poor farmers and show positive, sustainable impacts in other sectors as well. The smallholder farmers in the examined region face a special situation due to the developments in the sugarcane market. While dairy farming has already been proven as suitable income source for smallholder farmers, this thesis focuses on a comparison of different intensification paths and the respective income effects. In addition, the results of the survey should enable a broad insight and allow to gain an understanding for the farmers’ living and working conditions as well as the drivers that influence their farming strategies.

2.2 Agriculture and economic development

In many countries, economic development was accompanied by a diminishing share of agriculture in GDP as well as a decline of people being employed in the agricultural sector, while the importance of the manufacturing sector increased (ACET, 2017, p. 21). This section delivers some insights into the relationship of agriculture, productivity, and structural transformation, supported by a selection of development economic principles. After a description of the exemplary Asian Green Revolution reasons are being discussed why similar developments in SSA did not show analogue success to date.

2.2.1 Theories about agricultural transformation

Barrett et al. (2010) describe the 1950s and 1960s as initiation period for research in agricultural development, which became a meaningful branch of agricultural and development economics. They emphasize that many of the insights from then are still highly relevant. The classical theory based dual-sector model of economic growth by Lewis (1954) is commonly being used to explain economic development. In many by now high-income countries, the success of economic transformation was based on agricultural development (Barrett et al., 2010, pp.447). Lewis (1954) assumes an agricultural sector (originally defined as “subsistence sector”) where labor is unlimitedly available at a subsistence wage and workers migrate to the industrial sector (originally defined as “capitalist sector”) due to increased income possibilities. The agricultural sector provides food while the industrial sector produces everything else. As the industrial sector expands, the demand for food in the agricultural sector increases. The increased food demand causes a food price increase in the agricultural sector and in turn reduces profits in the industrial sector. Therefore, growth in the industrial sector is only profitable given a parallel growth in agricultural production to meet the increased food demand. Lewis explained a connection of industrial and agrarian revolutions and identified the cause for economies lacking growth in industrial development in a recessive agricultural sector (Lewis, 1954, pp.432). Nurkse (1953) recognizes the occurrence of this theory in the example of England’s industrial revolution in the 18th century. Parallel to the booming industrial production, the introduction of new crops caused an increase of agricultural productivity. Food production augmented and was demanded by the industrial labor force. Due to the rising productivity in agriculture, workers could be released and migrated to the industrial sector. Although fewer people worked in agricultural production, they produced more food and supplied the growing workforce in the industrial sector. Without the increased agricultural production, there would not have been enough food supply for the growing industrial workforce (as cited in Timmer, 1988, p.276). In the World Development Report of 1982, a comparison of actual agricultural and GDP growth rates is being presented. The rule for most of the observed countries was that a certain growth rate in agriculture was necessary to support an overall GDP growth. Subsequently, an expansion of agricultural production through technological change and trade created important output demands in other sectors. Farm households with increased incomes first asked for products related to their business, such as fertilizer, construction materials, or transportation. With further increasing incomes they also wanted to satisfy their demand for customer goods like clothing, processed foods, or bicycles and radios (WBG, 1982, p.44-46). This development is the underlying idea for supporting farmers to trigger an economic transformation process. After a period of ongoing growth in agriculture, a relative decline of the rapid productivity growth and a decline of people being employed in agriculture can be noted. As incomes in the industry and service sector grow more rapidly than they do in agriculture, farmers are being attracted and migrate. It is essential for governments to find the right balance and timing in supporting the agricultural sector, although the sector's relative importance seems to decline (Timmer, 1988, pp.277). Mellor argues that economies in SSA in the past followed economic transformation strategies and initial signs of growth could already be seen. However, after short periods with good agricultural growth a setback to the traditional, low agricultural growth rate has been noted which is the reason for the sluggish economic growth (Mellor, 2017, p.32).

The logic framework of the above-described process has been researched and amended over time, while the basic concept remained. Johnston and Mellor (1961) define five equally important roles to illustrate economic transformation: first, the food supply for domestic consumption increases; in the second phase agricultural labor is being released for industrial employment; then, the market for selling industrial output grows, which in turn leads to an increased supply of domestic savings and finally, foreign exchange earnings are being raised. By defining these five roles they highlight that the agricultural sector should not be seen solely as resource reservoir for supplying food and labor but as an equal contributor, essential for the successful economic transformation process (Johnston & Mellor, 1961, pp.590). Barrett et al. (2010) add that the population focuses on a modern and service-sector oriented economy in urban regions. Due to better health conditions, demographic transition leads to lower birth and death rates. The result of successful structural transformation is an economy, in which capital and labor productivity in agriculture are equalized with the other sectors (Barrett et al., 2010, p.451). Further important for Collier and Dercon (2014) is the aspect that not only urban but also coastal zones are essential and concentrate economic activity. The boost in agricultural labor productivity causes poverty reduction and makes the availability of inexpensive food increase (Collier & Dercon, 2014, p.92).

In the World Development Report of 2008, today's validity of Lewis' theory is being discussed. Between 1993 and 2005, the agricultural sector in SSA contributed a third to the overall GDP growth. As these countries' agricultural sectors are large, agriculture is crucial for the economic development. One part of the sector is the staple crop production to mainly supply the local market. The other part consists of non-staple crops, such as vegetables, flowers, or traditional commodities like coffee or tea, which is reserved for international trade and export. Staples remain, even in a globalized context, non-tradeable due to their regional consumption according to local customs (such as yams or cassava) or simply because of the missing ability to reach international markets due to transport and marketing costs. It would be an expensive strategy and is not a goal to import staples. Due to a shortage of foreign exchange, replacing cereals by imports is not possible and staple food production remains important in low-income countries. A productivity increase in the non-tradable staple crop sector also has a positive impact on poverty reduction, as the increased supply reduces the food prices. Subsequently, labor wages and input prices remain low, and the non-food tradable sector continues being competitive. Poor net-food buying households benefit from these lower prices if the saving from reduced food costs is higher than the deficit from reduced wage incomes. Additional to urban poor net food-byers also more than half of the rural poor households benefit, as they typically also need to buy food. The tradable agricultural sector faces an increased competition in the globalized context. There is still potential to further increase yields of coffee, vegetables, and flowers. Tradable agriculture can aggregate growth through foreign exchange, which in turn allows imports of inputs and capital goods. This is crucial for agriculture-based countries, while countries who export their mineral resources depend less on agricultural exports. As increased farmers' incomes are being spent on domestically produced goods and services, it in turn also creates a demand for them and fosters relevant links to processing, food marketing, and intermediate inputs and services. Globalization and inexpensive imports of manufactured goods in rural markets are also likely to have effects on these links. The rapid agricultural productivity growth in countries like China and India showed the effect of industrialization and poverty reduction could be achieved (WBG, 2007, pp.28-35).

Mellor (2017) discusses another aspect. For a successful economic transformation, the growth rate in agriculture needs to be higher than the population growth rate. He defines a natural growth rate in traditional agriculture at about three percent - similar or a little higher than the population growth rate, which is about two to three percent in low-income countries. To reach modernization, a catch-up mode with an agricultural growth rate at least twice the population growth rate would be necessary. Once a high-income status with a low population growth rate has been reached in an economy, the growth rate in agriculture declines to one or two percent (Mellor, 2017, pp.12). Mellor refers to Boserup (1965), who did fundamental research on the relation of food production and population growth. She states population growth being the independent variable that influences developments in agricultural technology and subsequently the amount of food being produced (Boserup, 1965, p.11). Her conclusion is that the rates of population growth and technological change must be similar. In history, various setbacks in population growth due to famines or wars could be noted. Simultaneously, in these times agricultural growth rates were low or even stagnating. When population density increased, the area of land under cultivation also did or the way of cultivation intensified through shortening of fallow periods, installing irrigation facilities, or increasing the number of harvests. On the contrary, when population density declined as people moved to less populated areas, some of the advanced agricultural techniques even got lost and the level of technology dropped. For a very rapid population growth, a much higher rate of intensification would become necessary and go along with agricultural revolution, as it happened in the 18th century in western Europe. Boserup concluded with the prognosis, that what occurred in the decades after 1950 would be described as "Indian Agrarian Revolution" from a future perspective (Boserup, 1965, pp.55-59). Indeed, what happened in Asia in the following period verified her idea (*see section 2.2.2*). In regard of this theory, due to the high population density in western Kenya, the precondition for productivity increases in agriculture would be given.

Collier and Dercon (2014) criticize the prevailing focus on smallholders and argue that resource allocation should take place in sectors with higher and various income opportunities to achieve an overall economic growth. The authors mention larger farm holdings as important places for carrying out experiments and leading technological process as well as profiting from economies of scale (Collier & Dercon, 2014, pp.96-98). That makes their position an antithesis to what has just been described as successful economic transformation in the historical context. Their research focuses on reasons why the economic transformation process did not happen yet in SSA, and one reason to explain it is the theory that too much support was being given to poor smallholder farmers. They further argue that the classical theory of economic growth being a result of smallholder agriculture growth due to the strong linkage of production and demands might have been true for closed economies, such as China was in the past. Today, in a globalized context and open markets the conditions are different and demand different growth strategies, supporting large-scale commercial investments and enabling more interactions between small and large farmers as well as vertical integration of enterprises across the value chain. The authors highlight that the comparison between the investments and the subsequent effect on the economy, for example in terms of GDP, is significant (Collier & Dercon, 2014, pp.96-99). As the topic of this thesis is about the support of smallholder farmers to induce an overall economic growth process it seemed relevant to include a contrary perspective as well. In the following examination of an example for economic development in Asia it is also being emphasized that small farmers were the important driver.

2.2.2 The Green Revolution

In this section, an overview of the Green Revolution (GR) is being presented. It is based on a summary provided by Hazell (2009) for a report about successful agricultural transformations by the International Food Policy Research Institute (IFPRI).

In the last century, many Asian countries were facing challenges like drought, hunger, malnutrition, and high population growth rates. In only 25 years from 1965 to 1990, the agricultural output doubled. This GR spread rapidly across Asia and instead of famine there was a food production surplus. Agriculture contributed to economic growth and people were lifted out of poverty. The recipe for this success story was the combination of an entire package: modern inputs (improved seeds, fertilizers, pesticides), public policies, agricultural research and development and improved rural infrastructure (irrigation, roads, farmer credit, price stabilization). Hazell (2009) states, that especially small farmers had an economic incentive to adopt this new package and demonstrated high efficiency. The increase in this sector illustrated a win-win situation favoring economic growth and poverty reduction. Initially, the research for high yielding varieties was focused on wheat and rice, which made Asian farmers applying the new technology rather fast. Later the developments included sorghum, millet, maize, cassava, and beans. The governments played an important role. In 1972, they used about 15% of their GDP for total public spending on agriculture (Rosegrant & Hazell, 2000, as cited in Hazell, 2009, p.3). This rate had to be sustained or even increased to be able to keep the process going. Investments in education, input delivery, credit, processing, storage, trade, and marketing capacities were necessary. The high yield increases enabled food production to rise faster than population growth did. The GR enabled a higher calory availability per person at a cheaper price. As poor farmers produced more, they had more food available for household consumption and sale. Agricultural employment was created, wages increased and through an overall economic growth, employment in the non-farm sector could also be stimulated. Furthermore, increased food production caused lower food prices in general (Hazell, 2009, pp.3). Hazell summarizes the important points that were crucial for the success of this GR. First, a package of inputs, credit and markets that was available and affordable for all farmers. Therefore, investments in research and development, extension services, roads, irrigation, power, and other infrastructure had to be provided by public and private institutions. These preconditions were already prepared in several decades before the GR finally took off. An economic environment that made adopting new technologies profitable for farmers was required as well as government policies and continued investments to sustain the achieved goals (Hazell, 2009, pp.20).

Besides all these positive aspects, there are some negative ones that are being mentioned repeatedly by various authors. Zeigler and Mohanty (2010) and Pingali (2012) summed up the high use of irrigation water, soil degradation, biodiversity loss, and environmental pollution due to mistakes in fertilizer and pesticide management (Zeigler & Mohanty, 2010, p.567; Pingali, 2012, p.12304).

Griffin (1979) highlighted that the newly introduced high yielding varieties favored more of the already large farmers, whose initial situation was better than the smallholders' in remote areas. New technologies were easier adoptable for them as they were able to access the necessary inputs, credits, technical knowledge, and an irrigation system – if the infrastructure not already existed yet. In his opinion, what happened was an output increase for marketable export crops instead of a higher production of relevant crops for local consumption. Rather than concentrating on welfare and poverty reduction for the poor, rural farm population, mechanization for large farmers was supported. With the ongoing mechanization and decreasing labor demand, further farm enlargement has been enabled (Griffin, 1979, pp.51). The fact that the GR often benefited farmers in a good economic situation more than small, poor farmers in remote areas has been highlighted frequently. Farmers depending on rain-fed agriculture had a disadvantage, as the improved seeds required irrigation for a suitable performance. Comparable to mechanization subsidies, which mainly supported farmers with larger landholdings (Dahlberg, 1979, 69; Zeigler & Mohanty, 2010, 568; Pingali, 2012, 12304). Dahlberg (1979) further questioned the background of the original idea that later became known as GR. It was primarily a project of the Rockefeller foundation to find out if improvements achieved by plant breeding could be transferred to various climate zones. An increased global food production with genetic and cultural improvement should be reached as fast as possible for the most important food and feed crops. What started 1941 in Mexico spread to South America and within the next decades to Asia and Africa. Research centers have been opened, foundations and governments have joined, and projects are still being carried out under the flagship of the Consultative Group for International Agricultural Research (CGIAR). Dahlberg (1979) emphasized, that these processes massively influenced not only agricultural research in developing countries, but subsequently also their societal and environmental future. Instead of developing local varieties from resistant seeds, which would have been locally adapted, the high-yielding seed varieties from overseas have been introduced. For him, the awareness about different agricultural structures (such as land ownership or wealth distribution) in developing countries has not been considered. Many side effects that appeared later could have been more visible before if this factor would have been part of the consciousness (Dahlberg, 1979, p.48). Dahlberg criticized this approach of simply exporting technologies and solutions from industrial countries and transforming foreign systems, as if there was only one globally right solution (Dahlberg, 1979, pp.89).

A selection of aspects related to the GR has been presented. Regardless, the GR supported an overall economic growth in many countries and increased agricultural productivity. The question might be raised why the GR has been successful in many Asian regions while the implementation in SSA did not break through yet and the anticipated yield increases still lag behind.

2.2.3 Obstacles for a Green Revolution in Sub-Saharan Africa

Financial commitment is an important factor for agricultural development. In many African countries a lack of rural infrastructure investments causes high transport and marketing costs (Hazell, 2009, p.23). While public spending on agriculture as percentage of GDP in SSA countries is around five to six percent, Asian countries spent around fifteen percent during the GR (Fan & Rao, 2003, p.8). Mellor (2017) mentions that especially small-scale ground water irrigation was an important factor for Asia's GR. While SSA has a large potential for irrigation, only six percent of the cultivated area is being irrigated (Mellor, 2017, p.173). For many farmers in SSA, due to high input- and low sales-prices, the shift to high-input high-output farming is not profitable. Therefore, well-targeted subsidy programs can have a substantial effect on new technology adoption. There were high subsidies on inputs in certain countries, but these efforts could not be sustained due to structural problems and governments had to stop the payments again (*see section 2.2.1*). Market liberalization policies including competition with cheap and subsidized food imports made it difficult for the domestic agricultural sector (Hazell, 2009, p.23).

The inputs to support GR technologies need to be available in due time. Belated delivery might lead to wrong application, which has a negative effect on yields and causes farmers to distrust the new technology and investment. Accompanying the farmers with good extension service and information transfer is vital to ensure correct utilization (ACET, 2017, pp.51-56). Pingali (2012) considers that research in the GR first did not focus on crops that are relevant in SSA. Exploration for maize took off in the late 1980s, which could be a reason for the delayed adoption. Evenson (2003) studied crop variety improvements and productivity effects and noticed that by 1998, adoption rates for improved varieties in SSA were still beneath 30%, while they exceeded 80% in Asia (as cited in Pingali, 2012, pp.12302).

The slow growing non-farm economy in rural areas is another issue. Due to mechanization, the agricultural sector demanded less manpower. Opportunities in the non-farm sector were not plentiful enough to absorb the people who were released by the agricultural sector, therefore rural unemployment increased. Migration to urban areas can also be a poverty reduction strategy, but if it happens at a higher pace than the growth in employment opportunities, either people move to low-paying jobs in cities or poverty is just being transferred rather than reduced, as one of the conditions for agricultural transformation is missing (Hazell, 2009, p.23; Pingali, 2012, p.12304).

Another argument discussed by Pingali is, that low population densities and the poor market infrastructure in SSA countries were not a suitable fundament for the GR. Contrary to Asian regions, where population densities have been higher back then already, which has changed meanwhile. In SSA the number of households increased, and land is a lot scarcer than it was in the last century (Pingali, 2012, p.12305). The underlying thought can be related to Boserup (1965), as discussed before. If land is unlimitedly available, there is no pressure to intensify production on the already existing plots (*see section 2.2.1*).

Hazell (2009) sums up that a GR for SSA is not about copying, rather developing flexible technologies to enable farmers to adapt to local conditions. Governments need to play the leading role to ensure coordinated, cost effective and socially profitable strategies and ensure affordable and sustained access for farmers to inputs, credit, and marketing services as well as competitive and reasonable, stable prices. Small farmers in bread-basket areas already having good infrastructure and market access shall be supported in increasing productivity, initiating the process of economic transformation, and making it a sustainable, long-term development (Hazell, 2009, p.24).

2.2.4 Reviewing agricultural development reports for Sub-Saharan Africa

The performance of agricultural production is being assessed regularly, regardless the country's economic development status. Various governmental, non-governmental, political, religious, private, or public organizations evaluate statistical data and publish reports. A selection of such reports is being used throughout this thesis to discuss smallholder farmers in SSA and their contribution to economic development. In the following section, some aspects about the course of this process in SSA are being presented.

Browsing the World Development Report of 1982, which focused on agriculture and economic development, it conveys the notion of having revealed that agriculture is the contributor to growth and agricultural progress is the crucial factor for economic transformation. Due to their efficient use of family labor and their effort to make investments and increase the agricultural output, especially small farmers are being highlighted. Important factors for success are: research to be able to adapt to local conditions and enable technological improvements, increased input use, and public investments in irrigation, transport, and marketing. The low production of agriculture in SSA is being labelled an infrastructural issue. Already in 1982, the awareness of the important role of agriculture for development and the understanding of the interrelation with poverty reduction existed (WBG, 1982, pp.5). Only 25 years later, the next World Development Report that focused on agriculture and development still had very similar key messages: smallholder driven agriculture has the potential to lead to overall economic growth and poverty reduction (WBG, 2007, p.44). Prevailing mentioned problems are rapid population growth, declining farm sizes, decreasing soil fertilities, and missed opportunities for income diversification while the agricultural growth rate is low. Irrigation, the education, and the health sector would require public investments. New aspects in 2008 are environmental services being provided from agriculture and the potential to cause environmental degradation (WBG, 2007, pp.7-10). The presented reasons why the recommendations of 1982 could not have been implemented were political challenges, such as trade liberalization or infrastructure investments. Governments are demanded to act decentralized and be closer to the people in rural areas, who must be given the right to political participation. For a successful economic development including agricultural transformation it requires the different sectors to cooperate at local, national, and global levels (WBG, 2007, pp.22-25).

The African Union (AU) launched the Comprehensive Africa Agriculture Development Programme (CAADP) to foster agriculture-led development. In 2003, they presented their goals in the “Maputo Declaration on Agriculture and Food Security in Africa”. The countries of the AU jointly phrased the vision of increasing government spending on agriculture to ten percent and reaching a productivity rate of six percent in the sector. With these measures they want to reach poverty reduction, end hunger, raise economic growth in the AU, and promote sustainable environmental management (AUC, 2017, s.p.).

Researching all these agricultural development aspects creates the feeling that the political tenor has been the same for decades: “We need economic development, and a productive agricultural sector can lead to economic growth.” The question why the success has not become visible yet, if all the processes are clear and the commitment is there, arises. The African Transformation Report of 2017 describes that the share of agriculture in SSA’s GDP is declining and instead of a growth in the manufacturing sector it can be noticed in low-value services in the informal sector instead. Still, about 25% is the agricultural share of SSA’s GDP, while the impact that agriculture contributes on GDP growth is rather small. The suggested topics for an improvement are an increased on-farm productivity as well as quality and quantity of the output to support processing, manufacturing, and various services along the agricultural value chain (ACET, 2017, p.21). In the present thesis, scenarios to increase on-farm productivities in the case study region are being assessed. As LP is the method being applied, an introduction is being given in the upcoming section.

2.3 Supporting production planning in agriculture by Linear Programming

The importance of progress and productivity increases for smallholder farmers in SSA has been stressed exhaustively so far. Zooming in and showing how these goals could be reached on farm-level is an aim of this thesis. A crucial aspect for the individual farmer's success, being reflected by income or productivity, is the decision about the deployment of available resources on the farm. Various ways of production planning exist, such as following traditional practices, intuition, past experiences, trial-and-error methods, or more advanced decision-making tools (Fendji et al., 2020, p.1). A strategic way to develop an optimal farm plan could be an LP application, which is being presented in the following section.

2.3.1 Introducing Linear Programming

Since the development of LP in the 1950s, agriculture has been a suitable field of application. Agricultural inputs, yields, and seasonal resource availabilties can be displayed and matched with resource endowments, new technologies, or changing market conditions. An advantage of LP is that it enables large scale analysis for an entire sector as well as small farm models for individual farmers. Economic contexts are typically part of such agricultural models (Hazell & Norton, 1986, pp.3-6). Resources and constraints of agricultural production are taken into account to determine the optimal mix of agricultural activities, subject to a certain objective. (Fendji et al., 2020, pp.7). The objective for the optimal solution is being laid down in advance. Maximizing the farmer's net revenue is a common objective – instead the objective could also be about minimizing environmental impacts, fulfilling a minimum production of a certain crop, or to achieve production requirements to receive subsidies. Some further examples are being mentioned in the consecutive section. A simple LP model according to Hazell and Norton (1986) requires to specify:

- all the possible farm activities (including resource requirements and production constraints, such as limits for certain crops)
- fixed resource constraints for the farm (as for instance maximum available land area or labor time)
- the respective economic parameters (such as prices or variable production costs, both can be used to estimate gross margins of the activities)

For example, an activity could be to feed a dairy cow, to plant Napier grass, maize, or bananas. It requires land and labor constraints of the farming family and the revenue of a liter of milk or a kilogram of maize. With the help of the LP model, the optimal production plan for such a farm can be calculated. Furthermore, crop sequencing could be included and applied (Hazell & Norton, 1986, pp.10). The mathematical way of formulating such an LP model after Hazell and Norton (1986) appears like this:

Objective function: max $Z = \sum_{j=1}^{n} c_j X_j$

Subject to: $\sum_{j=1}^{n} a_{ij} X_j \leq b_i$, for all i = 1 to m

$X_j \geq 0$, for all j = 1 to n

Z = total gross margin

X_j = the level of the *j*th farm activity, for example the acreage of maize grown. Let *n* express the number of possible farm activities, such as maize, sugarcane or potatoes, then *j* = 1 to *n*

c_j = the expected gross margin of one unit of the *j*th activity, such as USD per acre

a_{ij} = the quantity of the *i*th resource, such as available acres of land or man-days of labor, required to produce one unit of the *j*th activity. Let *m* denote the amount of farm resources, then *i* = 1 to *m*

b_i = the amount of the *i*th resource available, such as total available acres of land or man-days of labor, the right hand-side value

Assuming economic rationality, the farmer faces the primal LP problem: he or she is looking for the production plan with the largest possible total gross margin *Z*, without violation of the fixed resource constraints and without involving negative activity levels. The farmer wants to maximize the total gross margin of farming, taking all the available land and labor resources into account. None of the activities can have a negative value, if an activity is not going to be realized it has the value 0. The LP will show the farmer which farm activities to implement and the relevant shadow prices. Those indicate the change in the objective function variable for an additional unit of land or labor. The model will furthermore deal with the farmer's specific challenges – which production method to choose (producing silage or feeding cows with Napier grass), if factors shall be substituted (manual work by hiring a tractor), and if labor can better be distributed due to seasonal patterns of certain crops.

2.3.2 Some LP application examples for smallholder farming

Some examples of recent publications dealing with agricultural production problems are being presented in the following section. All of them apply the simple model structure LP to maximize net returns, some add the factor household consumption, which is also an important aspect in the LP application following later (*see section 3.6*).

Sofi et al. (2015) utilize the basic framework for a small crop production LP model with five cropping activities. The authors highlight that the estimation of the production coefficients is a challenging task in model formulation, but the efforts made are being recompensated with reasonable results. The crop production output is the objective function, land and labor coefficients are constraints. The result shows the optimum cropland allocation, implementing two of the five possible cropping activities. The authors did not include livestock and kept the model simple (Sofi et al., 2015, pp.165). An individual farm livelihood system was modeled by Majeke et al. (2013). The objective function is defined as maximizing total annual net returns. They added a food security aspect by including a household consumption constraint. In this model the limiting factor is operating capital. Only a part of the available land area can be cropped due to financial restrictions. As labor and land are sufficient, a capital increase would enable an increased land allocation. Under existing conditions, household consumption would be fulfilled, and the crop sales enable an almost 45% income increase (Majeke et al., 2013, p.33-35). Hildebrand and Cabrera (2003) give a guideline and present an overview about modeling smallholder farms with LP. They emphasize that especially smallholders in countries with low agricultural development have very limited resources, which makes the LP a suitable decision-making tool for them. Result evaluation needs to be done considering the different conditions that these farmers are facing. The perspective should enable a broader understanding of family and household structures, which might influence their reactions to new technologies, infrastructural changes, or policy incentives. For a subsistence farmer the farm is much more a home than a business or a job (Hildebrand & Cabrera, 2003, p.1). Mellaku et al. (2018) analyze smallholder productivity in connection with cropland allocation decisions and thereby meeting production goals for satisfying the household’s food requirements and using environmental resources sustainably. They link low smallholder productivity with the missing attention that is being given to cropland allocation decisions. A reference scenario shows the production data originating from the household survey, some of the farmers were not even able to emerge for their own consumption. The following LP application constraints were limiting land and credit resources. Allocating the cropland according to the LP results enables food supply for the household and doubling the profit potential (Mellaku et al., 2018, pp.1-5).

The following two studies include more elaborated LP applications and are being portrayed to show the range of possibilities for agricultural LP applications. Various environmental or nutrition-focused models are being implemented, furthermore, widespread applications respectively require more extensive data material. Kikuhara et al. (2009) developed a model to identify the optimal livestock production system by connecting dairy cattle and forage crop production. The four sub-models include optimization of nutrient requirements, diet formulation, herd management, and are finally combined to a whole farm optimization model. The authors emphasize that the results after each sub-model optimization do not always deliver the optimal base line for the whole farm model. In their example the optimum diet formulation does not go along with the utilization of home-grown feed, in some cases priorities need to be predefined (Kikuhara et al., 2009, pp.67-69). Moraes et al. (2012) developed a minimum cost diet formula for dairy cattle, with respect to environmental policies and impacts on nitrogen, mineral and methane levels. The herd is represented by different animal categories and their specific dietary needs. A model to minimize the diet cost is implemented, followed by a minimization of the sum of diet and CH_4 emission cost. Different levels of CH_4 emissions in the model runs show the different shadow prices and impacts. This model can be used to describe environmental impacts of livestock and food production and show potentials for more sustainable dairy production (Moraes et al., 2012, p.1267). Due to greenhouse gas-emissions and policy debates, models like this happen to become more relevant on an international level, regardless of a country's economic development.

The previous part was intended to represent the preparatory work for getting an idea of the thesis topic's larger setting. The context of smallholder farmers, increased productivity, and higher incomes has been illustrated by using economic-historic insights as well as current developments. The upcoming parts treat the realized household survey and the actual application of the LP model for analyzing income effects of options for productivity increases.

3. Material and methods

Productivity increases in agriculture, especially among smallholders, are being promoted as driver for economic growth *see section 2.2.1* (Rapsomanikis, 2015, p.12; AUC, 2017, s.p.; Mellor, 2017, p.11). The underlying objective of this thesis is to analyze the income effects of productivity increases on smallholder dairy farms in Kakamega County, Kenya. Data about agricultural production and the income situation of smallholder farms in this region either hardly exist or if so, are not available to the public. Therefore, a survey among farmers in Kakamega County was conducted. The research project for this thesis consists of the following stages:

- Questionnaire development: The questionnaire was being developed for collecting statistical data about the farming activities of the year 2018. A qualitative section in the interviews should help to reveal comprehensive information about the farmers' situations to be able to get a broader insight and understanding.
- Survey: Conducting interviews with farmers in the study region.
- Data analysis: After examining data about farming activities and the respective farming income in the year 2018, a qualitative analysis of the individual statements concerning the farmers' recent challenges and plans is being performed. A typical smallholder dairy farm for the year 2018 (TF18) is being deducted from the analyzed data.
- LP modeling: Scenarios to increase labor productivity of TF18 are being validated by an LP application. In addition to labor productivity, income effects are being explored.

Completing these tasks enables to get new insights about smallholder dairy farming in Kakamega County and to answer the research questions raised in this thesis (*see section 1.2*).

3.1 Study region

Kakamega County has an area of 3,033 km^2 and lies in Kenya's southwest (CGK, 2018c, p.1). According to the Population and Housing Census of 2019, the county was among the most populated (1.87 mio.) and showed a population density of 618 people per km^2 (KNBS, 2019b, pp.18;36). Two thirds of the population live in rural areas and the estimated population growth rate was 2.2% for 2009-2019, illustrating a decrease from 2.9% in the period 1999-2009 (KNBS, 2019a, p.6). Kenya's poverty rate has been declining from 47.2% to 36.1% in the last ten years, Kakamega County shows a rate of 35.8% (KNBS, 2018a, pp.44). Two different climates are present: tropical monsoon as well as tropical rainforest climate. The average temperature varies from 19.3°C to 21.7°C, the average precipitation from 1,678 to 2,000 mm. Kakamega town's elevation is 1,535 meters above sea-level (Merkel, 2019, s.p.).

The following data regarding agricultural production are an extract of the "Climate Risk Profile Kakamega County", which is provided by the Ministry of Agriculture, Livestock and Fisheries (2017). Climatic hazards such as drought and occasional floods are contributing to poverty and food insecurity. The county is a net importer of agricultural products. According to an FAO survey about food security (2016), 76% of the households have problems to cover their food needs due to poverty, small land sizes and a lack of market information. The total arable land area is 220,880 ha. Around 60% of the farms in Kakamega are small, mixed subsistence systems, large-scale farm holders manage an average acreage of four hectares. The main crops in the county are sugarcane, maize, bean, cassava, finger millet and sorghum. High input prices and long distances to input markets are the main constraints for farmers. Furthermore, they have limited access to market information, value addition technologies, formal savings, and agricultural credit. While access to climate information is given, there is only low capacity in responding to those climate shocks and early warnings. Agriculture is not a full-time employment, still it counts for the greatest employment in Kakamega County (756,711 people, according to a GoK-study from 2014) and is therefore an important economic factor. More than 50% of the farmers are rearing cattle – in 2016 145.8 mio. liters of milk and 364,000 kg of beef were produced. The milk yields vary, depending on breed and season, between 3.8 liters and 7.2 liters daily per cow. Farmers rely on rains for livestock feed and good milk production. Temperature increases and poorly distributed rainfalls influence the amount of milk being produced, for instance due to reduced pasture or a lack of refrigeration during transport. Subsequently, consumers receive less milk and farmers lose an income source. It is being highlighted, that farmers need to face these climatic insecurities and develop strategies to handle the issue. Droughts are also affecting sugarcane plantations. Especially for farmers in the southern part of the county the crop has an important meaning, as many of them have been relying on the cash-crop and through the local, government-owned sugar miller Mumias Sugar Company (MSC), prosperous economic development has been enabled for decades (MoAlf, 2017, pp.3-9).

According to the reports published on the MSC website, starting 2014 they incurred losses (MSC, 2015, p.7). The latest annual report from 2017 states that they faced an acute shortage in sugarcane and production dropping 65%. MSC linked the decrease with low rainfall and inadequate fertilizer application. The factory shut down in April 2017 for maintenance works and argues having financial problems. Since 2017, sugar imports have become duty free which affects increased imports and reinforced competition (MSC, 2017, p.19). Kweyu (2013) studied reasons why farmers in western Kenya ceased from sugarcane production. They mention high input costs (especially for fertilizer and cane transportation) and the discontinuation of incentives that MSC offered (such as free seed distribution or field days). Furthermore, the cash-crop was affecting the farmers' food security. Focusing 100% on sugarcane production and relying on the payments from the factory can be an issue if transactions are late or fail to appear (Kweyu, 2013, pp.1-9;16;52-54). Kioko (2015) explained Kenya's ailing sugar industry and the MSC-case with illegal imports, mismanagement, and corruption, being settled at the expense of farmers and workers (Kioko, 2015, s.p.). Recent articles talk about insolvency and a dispute about the revival between MSC, politicians, creditors, and investors (GoK, 2021, s.p.; Otenyo, 2021, s.p.). However, the county government encourages farmers to engage in dairy farming. This strategy shall improve food security, raise the farmers' incomes, and open new opportunities. The promoted production system is intensive zero-grazing with cut-and-carry feeding and higher milk outputs than traditional grazing systems generate (Boru & Ambunda, 2018, s.p.). Since 2015, in Kakamega's dairy sector 1,310 in-calf dairy cows have been distributed via the One Cow Initiative, two Smart Dairy units were established, AI-service availability improved and subsidized, and 433,461 cattle vaccinated against foot and mouth-disease (KCT, 2018, pp.17). One Cow Initiative provides farmers with a gifted dairy cow, the first female offspring must be passed on to another farmer who benefits from the program (CGK, 2018b, p.4). Smart Dairy was a concept from a Dutch company providing a "Farm in the Box" including all the equipment to run a western style dairy farm for up to 25 cows (Gundelach, 2017, s.p.). A further description about this concept is being given in *section 3.3*, as one of these farms has been visited. The annual milk production in the county has been projected to rise from 131 mio. liters in 2017 up to 200 mio. liters in 2022 (CGK, 2018a, p.197). One milk processing factory has already been established, a second one is being planned to create and maintain added value in the long term. To run the plants efficiently, the raw milk supply must be ensured however (Kenya News Agency, 2017, s.p.).

All these circumstances make Kakamega's smallholder dairy farmers with their strategies and income situation a relevant research topic. Especially the catchment area of MSC in the southern sub-counties around Mumias is of interest.

3.2 Farm survey questionnaire

The questionnaire was developed in cooperation with a student from Egerton University in Njoro (Nakuru, Kenya) in November and December 2018. This collaboration was facilitated through the international research project "SCARA" (Strengthening Capacities for Agricultural Education, Research and Adoption in Kenya). The project focuses on topics related to water for food and ICT (information and communication technologies) for efficient agricultural production. One project goal is to support students' cooperation in doing research projects and sharing knowledge on an international level. The research tool should cover detailed economic household and farming data and allow for a depth interview regarding the households' strategies. The goal was to be able to get an efficient and at the same time as detailed as possible insight into the farmers' situation and provide sufficient data for the analysis and LP application. In case of doubt, it was decided to design the questionnaire more exhaustive than to a lesser extent. As questionnaires for similar research projects already exist, available templates have been used for orientation and as a guideline (Muriithi, 2007, pp.63-76; WFP, 2011, s.p.). These surveys examined farmers' livelihoods and agricultural production in resembling settings.

The questionnaire can be found in *Appendix A*. It consists of six parts (A to F). The research period is the calendar year 2018. Part A is examining general data about the household and its location, part B records household composition, labor hours, monetary endowments and a short personal review and outlook for major changes, chances, and challenges for the agricultural enterprise. In part C, all relevant data about farmland and production of agricultural crops as well as animal feeds, divided into the two production terms (long and short rain season), is being collected. Part D gives an overview about livestock and details about dairy production are captured in section E. In part F, the support by institutional factors and extension services and the use of ICT in connection with the agricultural enterprise are being observed.

3.3 Data collection and processing

The geographical starting point for data collection was Kibabii University in Bungoma. Through connecting with an officer working for the NGO "Send a cow Kenya" (SAC) based in Bungoma, data collection in the study area could be arranged. The sample size was 30 households, and the interviews were conducted from February 4 to 12, 2019 in Kakamega County. Due to time restrictions, pre-testing of the research tool was not possible. The farms were chosen and accessed with the help of a local female peer group farmer working with SAC. Before starting the interview, each participant was asked to read and sign the consent form, as presented in *Appendix B*. The form consists of "Part A: Project Information" and "Part B: Certificate of Consent". It explains the research background and highlights the voluntary participation as well as the option of stopping the interview anytime. The note that all the given information is being kept confidential and handled anonymously is being completed with an information about entitled data use. One copy was signed and collected, another copy stayed with the interviewee and contains contact details for questions that might come up later. In the case of non-English speaking farmers (approximately 50% of the interviewees), the peer group farmer was translating from the local Swahili dialect to English. In the same manner she explained the consent form to the farmer in the local dialect before starting the interview. In total 30 farms were visited; 28 interviews took place on family-run small-scale farms. Two of the visited farms were bigger enterprises with more than 20 dairy cows and have been visited to get an idea of the structure of large-scale dairy farming in the observed region. Data was collected on one of the two larger farms. It was a Smart Dairy farm project that originated from a partnership of the Kakamega County government and the Dutch-based enterprise Smart Dairy. Due to the totally different farm structure, the data gained on this farm is not part of the overall data description. Rather, these findings are being used to model a larger-scale production scenario for cooperating smallholders in *section 4.4.3*. Compared to the way that most of the interviewed farmers are working, the Dutch concept is a lot more capital intense. Among other factors, that is due to the water and electricity demand. Most of the small farmers in the sample do not have these supplies available on their farms yet. Still, the conditions of the interviewed farmers meet exactly what is demanded from the Dutch concept: smallholder farmers forming a group and having at least ten acres of land together to provide animal feeds for keeping up to 25 dairy cows.

The data description (*see section 4.1*) presents 28 small-scale family-run dairy farms. Especially information gathered in part C cannot be taken as complete and precise for each household. In certain sections the questionnaire has been used as a guideline, in practice many questions were not answered as detailed as the questionnaire would have asked for it; the conversation had a more qualitative character. This fact is being indebted to the extent of the questionnaire, the incomplete data availability at the farms as well as the missing research tool pre-test. For example, certain interviews recorded labor times for land preparation and planting of maize and beans, while they were missing the labor times for harvesting. In certain crop cultures own seeds were used, while in others, seeds were bought but the input price has not been recorded.

The interviews were digitalized, analyzed, and visualized by using the software packages IBM SPSS Statistics 20 and Microsoft Office 365 Excel. Furthermore, GPS-locations of the visited farms have been saved on-site to create the map displaying the household locations (*see section 4.1.1*) with Google Maps. The locators (HH01 to HH30) have a symbolic character and are not being used in relation to any of the presented data for data protection reasons.

3.4 Qualitative data analysis

The two open questions about the farmers' recent challenges and plans enabled the option for conversation beyond pure data and farming practices and allowed some room for an emotional perspective. As Hildebrand and Cabrera (2003) stated about analyzing smallholder farms, due to these farmers' special situation a broader understanding of connections, inside and outside the household, is necessary (Hildebrand & Cabrera, 2003, p.1). To enable this understanding and accompany the results of the economic analysis, these narrative questions were part of the survey. A detailed understanding of the situation should be transmitted, and the interviewee shall be empowered to share her or his knowledge (Butina, 2015, p.1). Especially as the analysis was being done by a person who comes from a totally different cultural setting, valuable information that would remain hidden without this communicative and broadening tool could have been missed. The received answers have been categorized and interpreted based on content analysis according to Mühlfeld et al. (1981). The described procedure consists of six steps to extract the essence of a qualitative survey. Due to the small extent of the two questions in the study, this process was being shortened. The given statements were being clustered and summarized according to similar categories and logical context. These clusters are being presented, showing the counts of mentions. No limit for a maximum of statements given by each farmer has been defined. The statements and analysis are being presented in *table 2* at the end of *section 4.1.2*. Furthermore, a more detailed interpretation of this summary follows in *section 4.1.7*. At this point, data originating from the qualitative analysis are being combined with new insights that revealed during analyzing the other parts of the interviews. In this manner, an extensive view on the smallholder farmers' situations and driving factors for their farming strategies can be gained.

3.5 Selecting a typical smallholder farm in 2018

All the descriptive data of the sample is being used to represent a typical smallholder dairy farm in Kakamega County in the year 2018 (TF18, *see section 4.2*). Considering the sample size of 28 smallholder farmers, the statistical value of the output cannot be estimated very high. Supposing the following calculation including the facts presented before: there are 750,000 farmers in Kakamega County, about 50% of these farmers rear cattle (375,000) and 60% are smallholders (450,000). As it is not possible to say how many of them belong to the same group, the estimation might be set at 400,000 smallholder dairy farmers being the relevant basic population for this thesis. Standard statistical methods would suppose a confidence level of 95% and a margin of error of 5%. Therefore, a population of 400,000 results in an ideal sample size of 384, allowing for a higher margin of error would enable a smaller sample size of around 100 farms (Dattalo, 2008, pp.11-18;38-42). As this is not the case, the development of a typical smallholder dairy farm in Kakamega County 2018 is being carried out by applying a more qualitative approach.

Each farm is being individually analyzed in detail, and subsequently, similar characteristics that appear in most of the cases are being summarized. Due to the high variability in data, aspects that are present on 50% of the farms are considered, as a rule of thumb. Still, there might be elected cases when this rule needs to be adjusted. For example:

- Thirteen farmers generate an income from selling bananas. These are less than 50%, but as this activity has an important value for the farmers' incomes, it appears in the typical farm.
- Five of the interviewed farmers mention sugarcane in their activities and can generate an income from it. Sugarcane is not represented in the typical farm, due to the small group of farmers that practice cane farming.
- Fifteen farmers take advantage of the support from the NGO One Acre Fund (OAF) and buy their inputs with a loan given by the organization. As more than 50% of the farmers state to do this it is being represented in the typical farm.

General data about the household composition, labor times, and dairy activities are almost completely provided through the survey. As can be seen in the overview of the typical farm, presented in *section 4.2*, the final values are being supported and underlaid with the spread of values in the sample, displaying minimum, maximum, frequency, average, median, and standard deviation in the table. The values for the typical smallholder dairy farm as presented in the table are an estimation – being supported by the before mentioned spread of values in the sample as well as overall information gained from the individual interviews. This is even more relevant as data become sketchier for cropping activities in the lower part of the table, and the values are characterized to a higher degree by estimation.

Each of the activities shows a total annual labor time (for the LP model the times are being displayed for respective months, to identify the months where labor is scarce). Furthermore, the cropped area, variable cost (VC), produced yield, household use, and sales are being presented. The gross margins (GM) for each activity are being calculated with the following formula:

(Production – Household use) * Salesprice = Sales

Sales – Variable costs = *Gross margin*

Labor times of each activity are being summed up to identify the difference of available and used family labor. The smallholder family farms in the sample generally do not employ workers. Additionally hired labor is being included in the VC of each activity, the same is the case for mechanical land preparation cost. The next step is to identify the household's farm income, which is being done by summarizing the GM of all the activities carried out:

GM Maize + GM Beans + GM Bananas + GM Dairy = *Farm gross margin (farm income)*

The farm gross margin shall indicate the farming income as the base value for all the following analyses. Obviously, this value does not cover all aspects of full cost accounting. Gross margins do not cover any fixed cost, such as investment cost, buildings, herd restocking, or electricity. Furthermore, family labor is not being integrated in financial terms. The farm model supposes that the available labor hours exist on the farm for free. This approach is very simplified, although, it provides the essential information for the smallholder farm setting in this survey. Many of the farmers live in very simple conditions, which means there is no running water, electricity, or a concrete floor. The basic aspects covered with this formula exist on all the farms in the sample. Therefore, the simplification of the model enables comparability of the households in the sample. The value of the amount of food consumed by the household members has not been discussed with the farmers. It is therefore not part of the typical farm, TF18. As household consumption needs to be considered for a complete analysis, a calculatory value is being added in the LP below (*see section 4.3*), where an explanation and more details are given.

3.6 Linear Programming application

The next step for the analysis is transferring the generated data of TF18 to a software for running the LP. The software being used in this thesis is GAMS – The General Algebraic Modeling System, which is available online at *https://www.gams.com*. After defining a reference model for validation (RM), the results of the LP application are being used for comparing the different scenarios' income effects.

3.6.1 Reference model and validation

To enable the TF18 being transferred to GAMS, a basic mathematical formulation of the present problem needs to be done. The simple farm model according to Hazell and Norton (1986) has been described before (*see section 2.3.1*). For the RM of TF18, an additional model based on Majeke et al. (2013) is being used as basic framework. The mathematical formulation has been facilitated and does not show household consumption separately. The entire production can be sold at the market. Furthermore, labor time is being presented annually – in the model application in the software this is being done monthly to identify scarcities. According to the common way of referring to measurement units in Kenya, prices are being stated in Kenya Shillings (KES, 100 KES are about 0.80 EUR) and area is being measured in acres (1 acre equates 0.4 hectares). The activities, respective GM, labor time, and land demand are being presented in Table 1:

Table 1: Mathematical formulation of the reference model

	MaizeIC	BeansIC	Maize2	Bananas	Dairy
Gross margin KES/acre or cow	77,200	3,600	8,000	80,000	65,800
Labor demand hours/year	375	310	440	480	780
Land demand acres/year	1	1	1	1	1.125

The optimal farm plan to maximize the farm gross margin shall be calculated. Resource constraints that must be considered are the land size of 2.5 acres and a maximum available labor time of 4,500 hours. The farm has a maximum allowance of 0.25 acres for bananas due to unclear market conditions and the high GM (for further information see *section 4.1.3* and *section 4.3*).

The decision variables are being defined:

X_1 = acres allocated for MaizeIC

X_2 = acres allocated for BeansIC

X_3 = acres allocated for Maize2

X_4 = acres allocated for Bananas

X_5 = number of dairy cows

The mathematical formulation of the reference model is being presented here:

Max $Z = 77{,}200X_1 + 3{,}600X_2 + 8{,}000X_3 + 80{,}000X_4 + 65{,}800X_5$ (*objective function*)

Subject to $X_1 + X_2 + X_3 + X_4 + 1.125X_5 \leq 2.5$ (*crop land constraint*)

$375X_1 + 310X_2 + 440X_3 + 480X_4\ 780X_5 \leq 4{,}500$ (*labor constraint*)

$X_4 \leq 0.25$ (*banana constraint*)

$X_1 = X_2$ (*intercrop constraint*)

$X_1, X_2, X_3, X_4\ X_5 \geq 0$ (*non-negativity constraint*)

Model validation is necessary to find out if the developed model is reasonable and discovers possible advantages or debilities of the model, as stated by McCarl and Spreen (2002). They describe two validation approaches – one is examining if the model construction was done correctly, the other one compares model results with observations in the real world (McCarl & Spreen, 2002, pp.18.1-18.3). The latter approach is being applied in this thesis. A comparison between TF18 (*see section 4.2*) and the RM generated with the GAMS software (*see section 4.3*) is being performed. As the input data originate from the survey, the objective function and the generated farm income should be similar.

Hildebrand and Cabrera (2001) highlight that model creation is a step-by-step procedure and the different aspects are being altered in sequence. Therefore, it is made sure that the steps are comprehensible, feasibility is given, and the received solutions after single steps help to understand and improve the final model (Hildebrand & Cabrera, 2001, p.1). These recommendations are being considered creating the RM and modeling the scenarios, as described in the next section.

3.6.2 Productivity increasing strategies and identifying income effects

"Labor productivity should increase in smallholder households if goals for poverty reduction and elimination of hunger are to be met." (FAO, 2016, p.14). This statement originates from an FAO report treating productivity increases on smallholder farms to reach SDG-goals. These increases could be reached through higher yields and larger farm sizes, or a combination of both (FAO, 2016, p.14). Applying the logic of producing the same output and investing less labor time would also lead to increased labor productivity. Lukuyu et al. (2012) relate feed quality and inhibited performance of dairy farmers in East Africa. A focus on feed management and forage production and educating farmers about these topics and creating awareness could make an essential difference (Lukuyu et al., 2012, p.17). A smallholder farmer being asked how to increase the milk yield would probably answer "with an additional cow". Another aspect that is being named for creating increased productivity is modernization. Compared to the smallholder farmers in the sample, the Smart Dairy concept with more than twenty cows and milking machines represents a fundamentally different farming system compared to the current typical systems. All these aspects deliver the background to the formulation of three scenarios, how the farmer in TF18 could increase the productivity on her or his farm. For this purpose, the RM is being enhanced, according to the following scenarios:

- Increasing the number of dairy cows: A typical smallholder, owning 2.5 acres of land might have the opportunity to increase the herd size, especially if an increase of land area is an option.
- Intensifying the feeding ration: Training the typical smallholder in forage production and conservation or creating awareness for better feed management can be a way to increased milk yields.
- Establishing a farmer cooperation: The typical smallholder organizes a cooperation group to make an investment and manage a large-scale dairy farm together with the other farmers in the neighborhood. The farmers have a concept for sharing tasks, responsibilities, returns, and investments. This scenario is rather theoretic for an individual farmer like the one running TF18, as large investments are necessary. The idea can be a blueprint for NGOs, or other private or governmental institutions to support farmers in agricultural modernization.

The altered farming returns and labor time demands of the respective scenarios are being utilized to calculate productivity with the following formula.

Farming income / Labor time used = *Labor productivity*

Finally, labor productivity and the possible income changes are being compared and analyzed. To illustrate the approach of this thesis regarding the LP application, an overview of the process summarizing the described methodology in section 3.6 is being given in Figure 1.

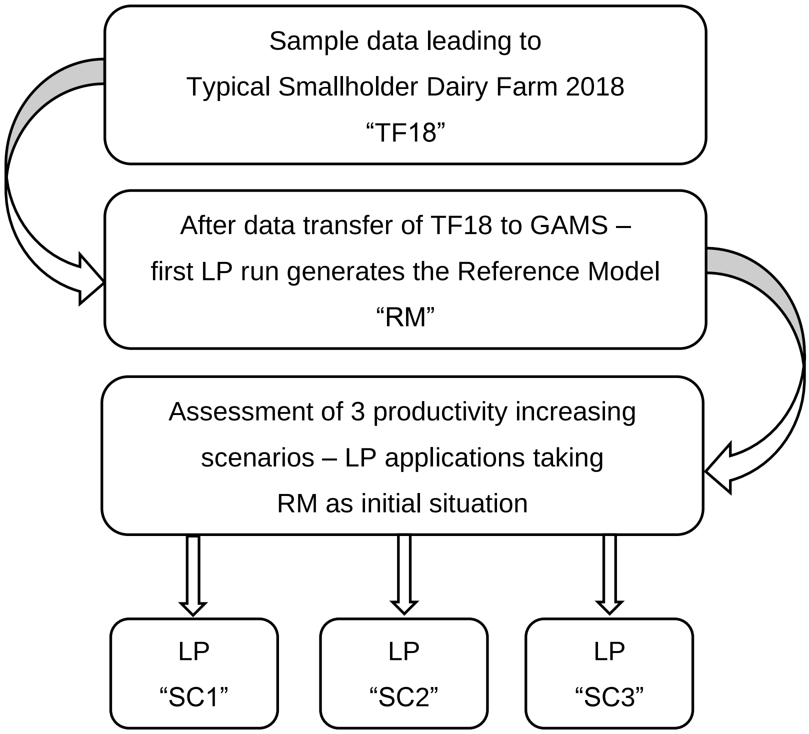

Figure 1: Description of LP application process (original illustration)

4. Results

4.1 Data description

4.1.1 Household identification

The average duration of an interview was 60 minutes, while the shortest took 40 and the longest 95 minutes. About 50% of the interviews were held in in Mumias East sub-county (14), 7 in Navakholo, 5 in Mumias West and 2 in Lurambi. Figure 2 (Source: Google Maps) shows the interviewed households' locations (including HH01 and HH07) and the location of Kakamega County on the Kenyan map:

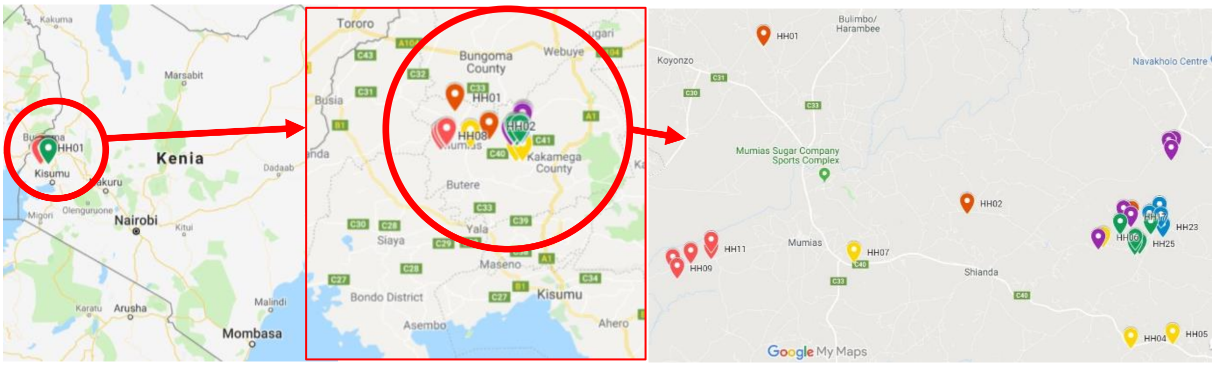

Figure 2: Location of Kakamega County & the interviewed households (Google Maps)

Each of the interviewed farmers is a member of at least one farmer group, 36% stated to be member of two (10), 21% are members of four (6) and one farmer is even participating in five different farmer groups. These groups are very common in Kenya and have various objectives, such as joint marketing of agricultural produce or taking part in NGO-supported projects. This is a way to encourage farmers to participate in corporately organized training activities, which can have an impact on their farm management. For further details in training participation *see section 4.1.6*. Due to the household selection in cooperation with the SAC peer group farmer, a majority of five households can be found in the sample for "Mumati Vulnerable Women Group" as well as for "Upendo Shinoyi Women Group". Each of the following groups is represented by two households: "Eshisene Local Poultry and Dairy Farming", "Isongo KDDC Vulnerable People" and "Isongo Local Poultry Group"; the other twelve households are members of different farmer groups. This selection also had an influence on household heads' gender being interviewed, 75% of the interviews (21) were held with women. A crucial number is the distance to the nearest market, as this is the place where the farmer would bring agricultural produce for selling in the local market or delivering milk for cooperative collection (which in turn influences the daily labor time for dairy). It was meant to note this number as distance in walking minutes, to have a very precise statement. Somehow the farmers were more comfortable giving this information in meters or kilometers. The distribution of the answers is being illustrated in Figure 3. The mean distance to the nearest market was 940 meters, the median value 650. Five farms (18%) were located less than 300 meters, 29% (8) of the farms were at 500 meters, 21% (6) at one kilometer, 14% (4) at two kilometers and one at three kilometers from the nearest market. In short, three quarters of the farmers in the sample have a market closer than one kilometer.

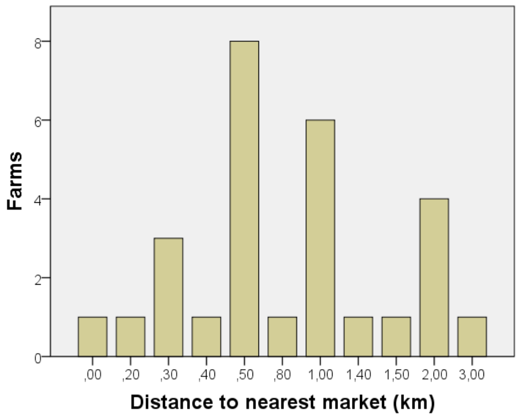

Figure 3: Distance of farm and nearest market

4.1.2 Household and overall farm composition

Family members

The household heads' age ranged between 32 and 63 years (average: 47; median: 45). The education level of the interviewed farmers was 21% Primary (6), 54% Secondary (15), 11% on Tertiary level (3), and 14% none (4). Half of the interviewed farmers had a farming experience of 12 to 15 years (average: 15.4 in a range of 5 to 40 years), experience in dairy farming was less than five years in 71% of the cases (5.83 being the average in a range of 0 to 18 years). The answers regarding age, education level and farming experience of the spouses were resembling, while it could be noted that for men the education level was at least Primary, while the 4 "none" were female participants. 19 farmers (68%) stated farming as their main and only occupation, 18% (5) are also self-employed and 14% (4) are holding down other forms of employment. Four of the self-employed farmers are running their own retail shops. Four female and one of the male farmers were widows and running the agricultural business alone or with the support of their children.

Labor time

The actual family labor hours per month were identified by asking about average daily working hours and the number of household members that have contributed to farm work. Children are generally available for more hours during school holidays (April, August, and December). The household composition (separated into male and female members, below the age of 6, from 6 to 13 and above 14 years) has also been recorded. The average household consists of 3 male (ranging from 1 to 7) and 3.5 female members (ranging from 1 to 10). In terms of farm work contribution on average one grown up person is working full-time, three people above the age of 14 part-time and two children (6-13 years old) are supporting farm work. Five of the farms employed permanent workers in 2018, which has an impact on available monthly labor hours and fixed costs. The average costs of permanent labor was 5,700 KES per month (median: 4,500). The permanent labor was added to stated family labor time and in total, the average farm household recorded 3,828 labor hours in 2018 (ranging from 1,536 to 10,512 hours; median: 4,553). Not included in this calculation was additionally hired labor, which has been added to the specific VC of the respective farming activity or crop culture. 22 farmers stated to hire casual workers for specific tasks. Others emphasized that this is not done generally but only if cash is available at the relevant time. Some farmers were not stating what they would pay for one day of labor as they hire somebody to fulfill an entire task in a specific time. For example, one acre of maize would be weeded in a week. The farmer pays 2,000 KES, while he or she doesn't care if one or four people finish the job. The data gained through the survey regarding daily wages were ranging from 100 to 300 KES with daily working times between one and seven hours. These values lead to an average wage of 51 KES per hour (median: 40), ranging from 17 to 150 KES per hour. An unskilled worker in 2018 had a minimum wage of 270 KES per day, according to Kenyan law (Wageindicator, 2021, s.p.). The stated data is overall corresponding to this value.

Financial situation

The off-farm income as stated in the questionnaires might not be continuous and correct. Some of the interviewed farmers answered this question easily, others were not willing to talk about this topic. One female farmer's husband is a policeman. She did not give any information about his income. Another farmer is running a dog breeding business next to his farm, he also did not talk about his business income as well as the retail shop owners, who did not share their business finances. Eight farmers stated off-farm incomes, from 5,000 to 180,000 KES in 2018 (average 69,325; median 50,000).

Exactly 15 of the farmers received a loan by the NGO "One Acre Fund" (OAF) in 2018. Three farmers had in addition to OAF a loan with another organization, one farmer had a loan given by the government. Instead of receiving the money in cash the farmers are being provided with the inputs that they need at the right time or provide additional things like solar panels or mobile phones. These loans are managed in a similar way – the farmer knows the sum that he owes and has one year to pay back the money, in whatever partial suitable payments. One farmer mentioned to pay back everything at once (paying the same sum as the other farmers do). The schemes of paying back were ranging from 100 or 300 per week up to 1,000 KES weekly or even monthly. The loans ranged from 9,000 to 41,225 KES (average: 17,868; mean: 15,000). While the subsidized inputs for one acre of maize and beans intercrop cost about KES 5,000 the smallest loan sum was KES 9,000. It included interest rates and handling fees. Many farmers added various goods provided by the NGOs to their packages (like solar lamps, solar panels, concentrates for feed, or specially prepared storage bags for maize), which increases the payback sum.

Review and outlook

To get a better insight into farming in this region and the challenges as well as the farmers' plans, two open questions were the last part of section B. First, the farmers were asked to think about conditions that changed in the last years and were encouraged to share thoughts concerning aspects that were challenging or had a positive impact. The outlook covered plans they already had as well as expectations of future aspects. The answers were analyzed and clustered to topics. *Table 2* gives an overview of statements related to past changes, chances, and challenges. *Table 3* presents the farmers' plans and outlook. The statements in the tables are being assigned to the respective topics. Additionally, for each statement in the sample the number of mentions is being given.

Table 2: Major changes, chances, and challenges of the interviewed farmers in the last five years

Topic	Statement	Count
CHANGES & CHANCES		
Crop farming	Manure application has become possible through owning a dairy cow, which led to improved soil fertility and higher crop yields	8
	Yields are increasing through the support of OAF	5
	New plantations were made possible (bananas, avocado, groundnuts, yams)	4
Dairy farming	Received a cow by SAC or another initiative, the option of selling milk increased the farming income	10
	Already passed on the heifer, which means that the next female heifer is an additional dairy cow	2
Household and family	Producing milk to feed the children	4
	Paying school fees with dairy income	4
	Building the house with dairy income	2
	Has been able to develop personality through income generation	1
	Buying clothes	1
Marketing and sales	Selling milk, bananas, poultry	7
	Forming and registering a new farmer group	1
	Market access through new road infrastructure	1
CHALLENGES		
Crop farming	Fall armyworm has been destroying maize, pests in general	6
	Lack of inputs due to lack of capital	2
Dairy farming	In the past, cows died, animals could fall sick	4
	Lack of knowledge in feed conservation techniques	2
	AI failure and low milk production	1
	Due to open grazing challenging disease and tick control	1
Household and family	Lost the partner	2
	Paying loans and fees	1
Marketing and sales	Marketing of produce can be a challenge	1
	Low maize price	1
Climate	Drought caused crop failure, lack of irrigation	5
	Lack of animal feeds during dry season	1
	Climate change	1

Table 3: Plans and outlook of the interviewed farmers for the next three years

Topic	Statement	Count
OUTLOOK		
Crop farming	giving up sugarcane plantation, starting sweet potato cultivation, starting tomato cultivation, growing Napier grass and sugarcane for molasses	5
	Achieving higher yields	1
	Being able to afford machinery (as the county government tractor has long waiting times for hiring)	1
Dairy farming	Having more dairy cows - more milk sales and a higher income	10
	Improving animal management and feeding	2
	Buying a pure-bred cow for higher milk production	1
Household and family	Being able to expand the farm with renting more land or buying another farmstead	7
	Building/finishing the house	5
	Having a better life with less work	5
	Paying education for my children	4
	Installing electricity on the farm	1
	Paying back a loan	1
Marketing and sales	More commercial farming	2
	Founding a new cooperative for marketing milk	2
	Getting a government cooling facility	1
New fields	Setting up an irrigation system on the farm through a borehole, buying a pump, looking for sponsorship to install irrigation facilities	7
	Engaging in goats and poultry farming	3
	Building a greenhouse	1
	Biogas	1

4.1.3 Farmland

Land size

The interviewed farmers stated to practice farming on 0.75 to 12 acres of land (average 3.1, median 2.75). 86% of the farmers had less than 4 acres of land, which is being visualized in Figure 4. Of the total cultivated land, twelve farmers (43%) had already rent in between 0.3 to 5.5 acres (average 1.4; median 1), which is being presented in Figure 5. Feed production for dairy animals took place on 0.25 to 4.13 acres (average 1.04). The most frequently practiced grazing system was zero-grazing, applied by 24 farmers (86%). Two farmers stated to practice semi zero-grazing, the other two kept their dairy cows pasturing. The farmers who mentioned to have pasture had 0.5, 1 and 5 acres available to graze their animals. 93% of the farmers answered that land for renting or buying would be available, only two farmers denied. Climate in the region typically allows two growing seasons. The rent prices actually paid by the 12 farmers who rented land in 2018 were ranging between 1,500 (only rented one season) and 36,000 KES (average 9,042; median 3,750). The farmers who did not rent land were also asked about potential rent prices. One acre was ranging from 3,000 to 12,500 KES for one year (mean 7,519; median 7,000). Buying one acre of land is 300,000 to 800,000 KES (average 514,231; median 500,000).

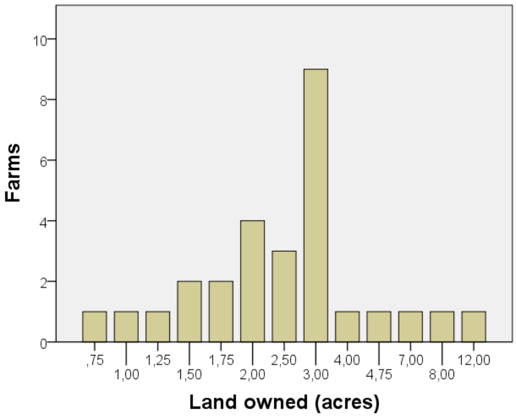

Figure 4: Acreage owned by farmers

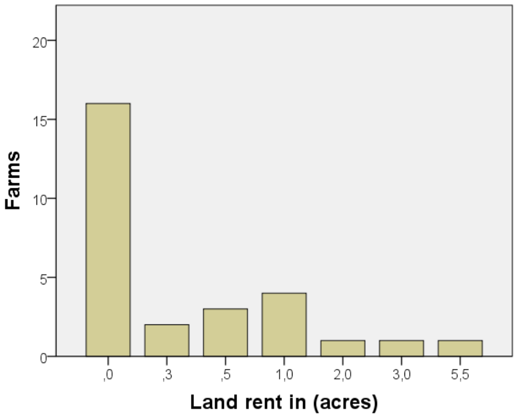

Figure 5: Acreage rented by farmers

Soil quality

12 farmers rated their overall soil quality with *Good*, 12 *Medium* and 4 farmers *Bad*. Many farmers mentioned that since having the cow, the soil quality and fertility remarkably improved. 27 farmers were aware of and practiced adding organic matter to prevent soil erosion. 16 (57%) and 15 (54%) of the interviewed farmers were aware of terracing and contour strip cropping to do so, which they mostly practiced by planting Napier grass. Only one farmer was applying zero-tillage, as he was taking part in a project with an NGO who supported that farming style.

Cultivated crops

In the following an overview of the surveyed crop production data will be given. Due to incomplete statements in many cases, some of the results are missing certain aspects. A separation into the long and short rain season is possible in some cases only, therefore data will be presented for the entire year (for instance if data about cultivation was noted separately but harvest amounts only given once). If the farmers were able to state labor times and tasks for the crops they were noted. Family labor and permanent labor was not calculated separately, for hired labor the total costs for the respective crop were calculated by the needed hours as the farmers stated and multiplied by the price for an hour of casual labor. In some cases, however, the costs for labor appear too high. To estimate gross margins for each crop, the sales were reduced by VC including these labor costs.

Maize-Beans

This mixed crop is the main cultivation activity in the region, especially in the first, the so-called "long-rain" season. These rains happen between April and June, the short rains last from October to December. The farmers' main focus is being put on the first season, as the rains in the second season are less productive some of them mentioned bad experiences in the past. Some farmers were repeating maize and beans in the second season, others were exchanging beans with soybeans or planting only maize in the second season. One farmer said, as the harvest was good in the first season, there has been fallow in the second one. 26 farmers cultivated maize and beans. Land preparation takes place until March, planting in March and April. 17 of the 26 farmers were not doing land preparation for the first season manually – ox-ploughing takes some hours and is 600 to 900 KES per acre, hiring a tractor can be up to 6,000 KES per acre and will be done a lot faster. The median mechanic land preparation price was 3,000 KES per acre. Eight of the farmers who planted maize and beans were hiring labor for land preparation. Normally weeding is performed twice before the beans harvest happens in June, combined with another topdressing in maize. The harvest for maize is taking place in late July or August. As the short rains start in October, land preparation and planting are being due by September. Some farmers who work manually just use the former beans-area for a second season maize-cropping, due to the limited time for land preparation. Analogue to the first season, weeding and topdressing is being done in October and November, the harvest in December. 12 of the 26 farmers were selling parts of their maize harvest, 10 farmers of their beans harvest. Of nine farmers who were able to earn a GM from their maize-beans cultivation, the average value was 28,900 KES. After this sample, the average maize harvest on one acre of maize-beans would be 1,250 kg maize and about 140 kg beans. Farmers mentioned that input prices were too high and the price to sell too low. One kg of beans would sell for approximately 75 KES, one kg of maize for 25 KES. That results in a GM of 41,750 KES for one acre, given that labor is provided by the family and there are no factors like drought or pests decreasing the harvest. The acreage for maize-beans intercropping ranged from 0.13 to 5.5 acres (average: 1.2; median: 1), VC were at 17,634 KES (median: 8,025). Assuming input costs of 5,000 KES per acre and adding labor and mechanic land preparation, this seems reasonable. Correct storage to prevent post-harvest losses is important. Another factor included in the VC was storage chemical or specially prepared plastic bags for storing, provided by OAF (250 KES for a bag of 90 kg of maize).

Bananas

Twelve farmers were cultivating between 14 and 120 stems. SAC promoted banana plantation in the last years and gave the plants to the farmers for free. None of the farmers was able to state VC or the amount of time spent for banana cultivation, an estimation resulted in 32 labor hours per month for an area of one acre or about 200 stems, as bananas are not very labor intense. The additionally generated GM was between 10,700 and 210,600 KES (average: 40,680; median: 20,375).

Sugarcane

Farmers who own bigger parcels of land or could afford to rent or buy additional land were cultivating sugarcane. Eight farmers had sugarcane plantations, two of them just stated the area but no more details. The plantations were between 0.25 and 10 acres. Six of the farmers were cutting and selling cane in 2018, two only started new plantations and therefore just had investment costs but no income. The generated GM was between 26,200 and 121,300 KES per acre and was mainly depending on the amount of harvest and transport costs to be paid.

Groundnuts

Six farmers cultivated groundnuts, four of them also sold them. The cultivation acreage was between 0.25 and 3 acres. Two households planted groundnuts in the second season after maize-beans and achieved a GM of 18,000 KES.

Sweet Potatoes

Four farmers were talking about their sweet potato planting activities. Two of these four farmers were selling sweet potato vines to other dairy farmers, as they are a popular fodder crop for cows. The GM of these sales was 12,000 and 15,000 KES. The farmer who was only selling the potatoes could not achieved a positive return, the other one just planted for household consumption.

Soybeans

Five farmers grew soybeans on an acreage of 0.25 to 1 acre. One harvested 40 kg on 0.25 acre in one season, the other farmer had 60 kg on 0.25 acres after two seasons. They did not sell the soybeans but used them as animal feed.

Vegetables

Three farmers were growing and selling vegetables and earned a GM of 9,000, 9,600 and 12,000 KES in 2018. Most of the farmers planted some vegetables for household consumption, these details have not been noted.

Others

These "other" crops were cultivated by a small number of farmers or lack a lot of information. One farmer planted a nut resembling peanuts (the right translation was missing) on 0.25 acres and sold 30 kg for 7,500 KES. One farmer planted sorghum on 1.5 acres, he sold 180 kg for 1,500 KES. One farmer planted yams on 0.5 acres and sold them for 4,550 KES. Similarly, "other sales" were recorded. One farmer had an extra income by selling poultry (6,000 KES) and fish (10,000 KES), another one earned 21,000 KES by selling manure.

Fodder crops

The amount of fodder harvested or given to animals was almost not tangible in the interviews. Some were talking about wheelbarrows, others measuring sacks (a standard sack of chopped Napier grass equates 36 kg, for details about dairy farming *see 2.1.2*). Most of the farmers planted Napier grass. Additionally, many farmers have a variety of desmodium, sweet potato vines and other forage legumes as well. These cultures would be planted once and then cut and carry fed for more than two seasons, as the plantations are perennial. Fodder conservation is not very common yet for the interviewed small-scale farmers. One farmer stated to use urea for fertilizing forage land. There was only one farmer giving comprehensive information about hay (labor time) and silage making. This farmer does silage on a big scale, instead of planting maize and beans his two acres were dedicated to silage-making for four cows. Including fertilizers, molasses, transport, material, and labor he spent 32,788 KES.

4.1.4 Livestock

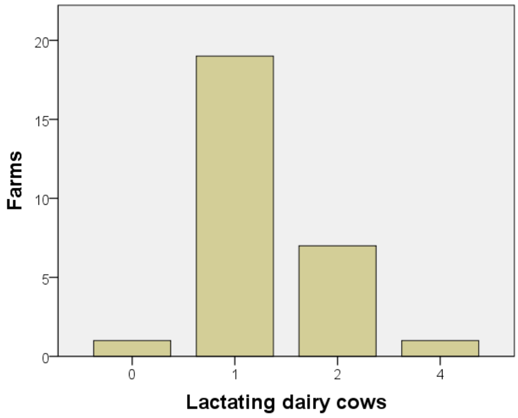

Figure 6: Number of lactating dairy cows per farm

All the dairy cows on the visited farms were cross bred cows. The number of lactating and non-lactating cows as well as calves was noted. All the other livestock on the farm was not recorded. The farmer was asked to give an estimation about the value of the dairy cow if it would be sold on the next day. The estimated value of the dairy cows was between 25,000 and 200,000 KES (average: 77,600; median 70,000). Figure 6 shows that the interviewed farmers were keeping one to four lactating dairy cows. One was not lactating yet at the time of the interview – this has been considered and the cow has been excluded and does not affect the analysis. Nine farmers had a heifer. Half of the farmers had one calf, three farmers two and two farmers three calves. The total number of cattle present on the farms was between one and five animals: 43% had two (12), 21% four (6) and 18% 1 (5).

4.1.5 Dairy

Labor time

The farmers were asked about the average time they spent each day (seven days per week) to care for their dairy animals, including time spent for calves, fetching water, arranging cut and carry feeding, milking manually, and delivering the milk to the cooperative collection point or the market. Daily labor times were ranging from two to ten hours (median: 4). Cut down to daily labor times per animal, including calves, farmers talked about 0.75 to 4 hours (median: 2 hours).

Milk yield and sales

The farmers stated daily average milk yields per cow of 2.25 to 23.5 liters (average 8.1; median 7.75). Household consumption – including potentially feeding a calf – was between 1 and 15.5 liters (average 3.5; median 2.75). The total amount of milk sold was between 1 and 32 liters (average 6.9; median 6). To be able to compare the households with each other and calculate the annual milk amounts, it was necessary to put the daily milk amounts in relation to one year. Milking periods were different on the farms, some farms even milked the cow more than one year due to gestation problems. If the milking period was stated in the interview, for example ten liters daily production and a milking period of eight months, these daily 10 liters were put in relation to twelve months, which makes 6.7 daily liters throughout the year. To simplify this calculation, one year was assumed with 360 days. Some of the farmers did not give an information about the milking period, so eleven months were assumed for a case like this: a daily average of 5 liters in eleven months makes 4.6 liters in twelve months. In this way, all the farms can be compared, and annual milk sales can be calculated more easily. After this calculation, the daily milk yield per farm ranged from 1.8 to 36.7 liters (average 8.4; median 7). Thereof, household consumption was discounted, and the total amount of milk sold is this daily, reduced, and standardized value times 360, which resulted in an average of 246 and a median of 198 liters. The milk price the farmers earned is rather constant. If the farmer delivered to a cooperative, the sales price per liter was 40 KES. This was the case for 17 farms, two farms received 45 KES instead of 40 KES. Seven farmers achieved 150% of this price – they were selling for 60 KES per liter on the local market. Three of the farmers who were delivering to cooperatives were selling a certain amount of milk to the cooperative and an additional amount locally. Five of the farmers processed the milk before selling. A fermented sour milk that is called “Mala”. It is being made of the milk that remains for household use, therefore these farmers could not state detailed quantities. Processing and direct marketing at local markets generated an additional income of 5,000 to 36,000 KES per year. In total the dairy income was between 19,680 to 440,600 KES (average: 97,583; median 77,085). Thereof the VC for dairy needed to be paid. This information was given a lot more precise than the information about crops. The values were ranging between 9,700 and 73,400 KES (average: 33,666; median: 29,957). The stated VC cover: feed concentrates (e.g. dairy meal or salt licks), health and breeding costs (e.g. AI, bull-services, dehorning, spraying against ticks, deworming, veterinary services, vaccinations), milking jelly, fodder purchases (e.g. hay or grass), and feed conservation costs (e.g. molasses and polythene bags). Not stated by the farmers and therefore not included in the cost calculation are: herd replacement, animal sales, depreciation, equipment, electricity, and water. Due to the simple standards of the visited farms, most of these assets were not relevant for the interviewed farmers.

Fractionally for one cow, a farmer was able to generate an income of about 80,000 KES and spent about 30,000 KES for VC. This results in a GM of 50,000 KES created by the dairy activity. Of course, these values depend on many factors (such as animal and feed management, milk price, or the animals’ condition) and do not include fixed costs. Three farmers were not able to generate a GM as they did not sell any milk, they either used it for household consumption or did not have a lactating cow yet. Another three farmers had costs that were overshooting their dairy income. Reasons could be gestation problems (costs of AI are rising and milk sales declining) or other health issues. The 22 farmers with a positive GM earned on average 75,668 KES (median 42,167) with their dairy animals.

4.1.6 Institutional factors and extension services

Dairy intervention programs

Of the 28 interviewed farmers, 22 were taking part in the SAC program and received a dairy cow by SAC. Two farmers received the dairy cow from another program (the governmental “One Cow Initiative”, and “KDDC” by WBG). Two of the interviewed farmers bought a dairy cow at their own expense. 93% (26 out of 28) of the farmers benefited from a dairy intervention program. The county government supported and subsidized the use of AI – all the farmers had access to subsidized AI, still some of them did not use it as they wanted to have different qualities, sexed semen, or preferred bull services.

Extension services

The farmers received regular visits from governmental and NGO extension officers. Nobody mentioned private extension visits. Seven farmers (25%) stated governmental extension officers’ visits once in three months, seven farmers received them monthly and seven farmers got even more visits. Four farmers (14%) had visits twice a year and one stated to having had one visit only, one did not have any governmental extension visits. All the 28 households were also a target group for NGO visits, as everybody was either covered by SAC, OAF, or other dairy programs. Still, seven farmers (25%) did not receive any NGO visits. Four farmers had a visit between once and four times in 2018 (14%), three had monthly visits (11%) and 13 farmers (46%) had visits even more often. Farmer trainings were being held very frequently. Five farmers (18%) mentioned trainings each month, 17 (61%) said it were even more than that. And the farmers were attending these – only two farmers never went (7%). Five farmers (18%) attended a training once or twice; six farmers three times (21%) and 50% (14 farmers) attended more than three times. In the following question, farmers were asked if these trainings showed any impact in their agricultural practice. As the statements were very numerous and eclectic, they were clustered appealing to the method applied in section 4.1.2. Table 4 shows the result of the analysis.

Table 4: Improved topics after trainings according to the farmers' statements

Topic	Statement	Count
TRAINING IMPACT		
Crop management	Soil conservation methods: mulching, terrace digging, handling of manure and organic waste	4
	Planted bananas	4
	Started new crops: horticulture, roselia	2
	Planting technologies: Awareness for early land preparation and planting	2
	Received new crops from the NGO	1
	Push-pull farming	1
	Training in maize storage	1
Animal management	General animal management training	7
	Awareness for a clean environment for the animal	3
	Building zero grazing unit	2
	Improved milk production and hygiene	2
Dairy feed management	Trainings for planting Napier, desmodium, sweet potato vines	7
	General dairy feed management training	3
	Fodder conservation techniques to prevent shortages, hay and silage making	3
Vegetable cultivation	Planting vegetables	3
	Starting a keyhole garden	2
	Double digging	1

In the following question the farmers were asked about their preferred source of advice in agricultural questions. The possible options were being given: farmer group, family/neighbors, cooperative, governmental extension service, private extension service, NGO, media. It was possible to state more than one answer and the distribution in the sample looked like this: 15 farmers stated government extension, 13 farmers stated the farmer group and family/neighbors. Media was named by 12 farmers and 11 stated NGOs. The cooperative per se was not mentioned as source of information and the farmers would not ask a private extension officer.

The next question was about the farmers' media use, e.g. if they had access and which channels they used for getting information about their farming activities (such as special TV programs, mobile phone apps or SMS services). The answers presented in Figure 7 show clearly that many farmers already use mobile phones, which could be a big chance for information and education in rural areas.

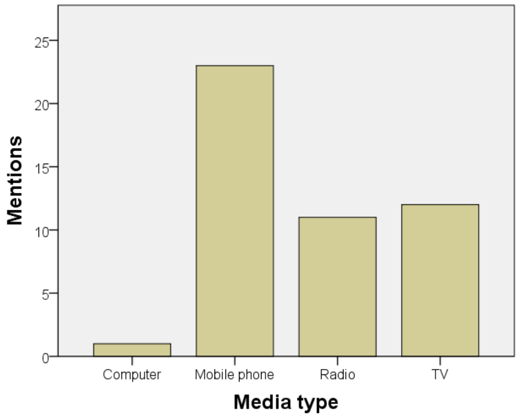

Figure 7: Preferred media channels for information

The farmers were asked if there has ever been a change in their agricultural practice after consulting one of these multimedia resources. Again, the method of clustering and summarizing has been carried out and the statements are being presented in Table 5.

Table 5: Media impact changing agricultural practice according to the farmers' statements

Topic	Statement	Count
MEDIA IMPACT		
General	Information source (Radio, TV, smartphone, google, reading a magazine)	5
	Weather information per SMS (e.g. from Kakamega County official service)	2
	Information about new activities, seen on TV and heard on the radio: duck rearing, fish ponds, poultry keeping	3
	Market prices SMS service (e.g. Kakamega County official service)	1
	SMS reminder for loan payment	1
Crop farming	SMS reminder to be on time with: buying inputs, start planting earlier, buy pesticides against army fallworm	6
	Started new plantations after saw in TV/heard on radio: banana, maize, beans	4
	Received information in TV/radio about fertilizer use and tillage	3
Dairy farming	Information about feeding the dairy cow (Napier planting, sweet potato vines, total mixed ration formulation) and feeding the calf	8
	Bought milking salve after seen on Shamba Shape-Up	3
	Building the dairy cow unit and its facilities: feeding trough, cow mattress	3
	Decided for exotic breeds instead of local ones	1
	Using ICow – receiving weekly SMS service, relevant information	1
	Spraying dairy cow – tick prevention	1
	Cow delivery – received veterinary help on the phone	1

Being asked if the farmers would prefer somebody visiting the farm and talking to them or showing some new techniques, only one farmer stated to prefer the multimedia alternative to contact somebody on the phone or try to get an information online. 27 farmers said they prefer the face-to-face consulting situation.

4.1.7 Socio-economic aspects resulting from data analysis

In the following section, an interpretation is being taken on the answers given to the question about changes and challenges in the last five years and the farmers' plans for the upcoming three years. Many of the interviewed farmers started dairy farming recently and profited from NGOs who supported them. Some of the statements stood out as they were mentioned repeatedly and seem to make an important difference for the farmers. Besides the impact on milk yields, food security and income, being given a dairy cow enables higher crop yields due to increased soil quality through manure application. NGOs are also helping with input procurement and support the farmers by educating them about animal management and different crop varieties. Farmers being successful with their dairy business talked about the option of increasing milk production further, to increase incomes. They wish to receive additional dairy cows, improve their animal management and feeding strategies, expand their farm size, and make investments for mechanization. There seemed only one topic, where the farmers had difficulties in accepting SAC's opinion about the economic aspect of dairy farming. The NGO advices farmers to get rid of male calves as well as older dairy cows that have health issues like gestation problems since these animals need attention, time and money and do not help in generating a regular income. The farmers, however, are happy and proud of their animals – male calves are being seen like a savings account, which could for instance be used as dowry. One farmer explained that if an intervention officer would show up, she would hide her animal in another farmer's place, as she was supposed not to have it. Overall, they see specialization in dairy farming as a positive future scenario for their farms and households. Personal aspects that were mentioned were an overall "better" life, enabling education and paying school fees for their children and improving the family's living conditions by upgrading the house. One statement was only expressed once but seems to have a high importance and was valid for many of the farmers, especially the female ones: "The dairy cow enables income generation and thus helps me to develop my personality." An aspect that does not so much appear in values like income, but even more makes a difference, for instance in having more equal rights in the family's decision-making process or acting as role model, especially for girls, in the next generations. Some additional topics that were brought forward are being discussed in the following.

Part-time or full-time commercial farming

Some of the farmers in the sample had additional income sources or a spouse with a regular income. This fact makes the farmer more independent and even seems to make the farm business more successful, as the availability of cash is less an obstacle than if the household depends on the farm income alone. Farmers who were running their own shop achieved a 50% higher milk price than the farmers selling to the cooperative, and input procurement was easier for them. Compared to school fees, farming input costs and the annual dairy income generated through one cow, the money earned additionally outside the farm can be a very important part of a farm household’s livelihood. Especially in years with difficult weather conditions or other reasons for harvest losses, a variety of income sources increases the farmer’s resilience. Like structural change developments already showed in other regions, the option to abandon agricultural production and move to a sector where a higher income could be generated seems reasonable, assuming that jobs are available, and food can be purchased from the market. At the same time, it must be considered that a successful farmer can potentially earn a higher income than being dependent on wage from non-qualified labor, as Siegal (2017) discussed in a study that assessed the impacts of OAFs support (Siegal, 2017, p.18).

Polygamy

An interesting fact that has not been concerned when developing the questionnaire is that some wives are not the only wives of their husbands. Polygamy is a present topic in many African regions. In Kakamega County, according to the household survey 2015-2016, about 15% of the marriages were polygamous (KNBS, 2017, p.7). Women in such a situation are more responsible for ensuring the livelihood of their families, while the men are moving between households and in many cases are not contributing financially to raising their children. One farmer’s husband was talking about “the farm on the other side” during the interview. It was explained by the translator afterwards as being the farm of one of the other wives of this man. This farm is economically seen completely independent of “this side’s farm”, while the several wives live in proximity to one another. Men having polygamous marriages often cannot cover for several families, therefore polygamy has the potential to aggravate poverty and economic pressure on women. Children grow up impoverished and their mothers suffer emotionally. Men do not need the approval of their wives to marry again, sometimes they do not even know about it. Especially when the marriages are customary and not registered the woman is in an unfavorable position. For this reason, the call from women to legalize and enforce the registration of customary polygamous marriages is present. It would enable the wives to claim child maintenance and alimonies and influence societal awareness (Bhalla, 2018, s.p.).

Loans

As most of the farmers do not have regular bank accounts, the simple and uncomplicated loan system provided by the NGOs seems very beneficial to them. They receive inputs instead of cash, there is no risk of spending the money in a different way. One farmer alone cannot apply for a loan, they must get together in groups to do so. Therefore, a kind of “social pressure” builds up, if a farmer would not cooperate with the group, the group probably would not accept this farmer in the following year anymore. The OAF groups also pool their labor for certain activities like planting or harvesting, so each group member has increased labor time available at no additional cost – the condition is to be available to support the other group members as well. This system minimizes weather risks, nobody needs to work alone and overall, tasks can be finished faster. All the farmers who are part of an OAF group explained the system in the same way, none of them mentioned having problems in organizing labor time management. The big advantage is that the inputs are being provided at the right time and the farmers can pay back the money in a flexible way. Additionally, farmers who are in such a program and need to manage to pay back a loan tend to have a higher awareness for keeping a household budget and seeing the importance of financial tools like bank accounts (Siegal, 2017, p.21).

Cropping activities

<u>Maize-beans intercrop</u>

Only two households of the sample did not cultivate the maize-bean intercrop. As “ugali”, the region’s staple food, consists of maize meal, each household has a demand for maize. It seems most of the farmers do not consider replacing the maize-bean intercrop, as they need the harvest anyway for the household and can easily sell an excess production. OAF is supporting the farmers with the inputs for the maize-bean intercrop, as this is the most common cropping activity in the region. The decision what to plant considers balancing household food security and market dependency. If the farmer would decide to use the land for producing additional feedstuffs for the dairy cow, milk production and the resulting income would have to increase to the extent that covers at least the amount of maize and beans, that were not produced and would need to be bought on the market. The farmers also mentioned that the input prices were too high compared to what they would earn by selling maize. Another challenge is the right time to sell, as the price is rising as the next harvest comes closer, the risk of spoilage and pests also does, and appropriate storage is crucial. The maize-beans intercrop is the standard cropping activity in the first season. The answers what happened on the field in the second season showed a higher variety. While some farmers repeated the intercrop, others were exchanging beans with soybeans or planted maize only. One farmer answered that he decided to leave the field fallow as the harvest has been good in the first season. Farmers tended to say that the second season is a lot more difficult concerning the conditions, therefore they put their focus on the first one.

Sugarcane

The area around Mumias in Kakamega County was formerly known as a sugarcane region. MSC was an important employer and bought the farmers' cane. Some aspects about the ongoing developments in Kenya's sugarcane industry and especially the struggle about MSC is being discussed in *section 3.1*. The company buildings of MSC are still there, and it seems that some farmers are going back or are still planting sugarcane. In the interviews, some of the farmers talked about their negative experiences with the company, as they did not receive various payments in the past. That is why they prefer milk production, as they can use milk for their own household and easily sell excess production. For sugarcane, they were depending on the company. The crop also favors soil erosion and nutrient depletion. Farmers who still own bigger parcels of land or can afford to rent or buy additional land are still cultivating sugarcane. One of them mentioned, that it is not sure if he is going to be paid for his produce on time and said that the entire business is not as reliable as it was in the past.

Bananas

Banana plants have been distributed by the NGOs and the farmers did not mention costs related to them. They would not need a lot of maintenance or labor time. Some farmers were able to sell bananas in the market, but the generated income varied a lot. It is difficult to make an estimation about a reasonable quantity that could be sold, as the information given by the farmers was not consistent.

4.2 Typical smallholder dairy farm in Kakamega County 2018 – "TF18"

A typical farm covering all the agricultural activities carried out in 2018 and the respective GMs is being described in this section. Averages, median values, and certain aspects observed during the interviews have been combined to develop this typical farm. *Table 6* represents the typical farm's characteristics and summarizes the agricultural activities. On the right-hand side of the table the spread of values in the sample is being shown to give additional information and make the value estimation traceable.

A married couple, being about 45 years old, is running the farm. It is their main income source and the husband's father and the 15 years old daughter help part-time on the farm. The two sons aged 9 and 11 contribute to farm labor during school holidays. The farmer graduated from Secondary, his wife from Primary School. They have been running the farm for about 15 years, 3 years ago they started dairy farming. The farmers are participating in two local farmer groups – one from SAC, which helped them to receive the dairy cow and the other one from

OAF, to get the loan for inputs and pool labor to help each other working on the fields. The nearest market is located about 700 meters from the farm. The cooperation with the other farmers from the OAF group in combination with family labor make labor hours abundant. Hence, the farm does not need additional hired labor in a typical year. Hired labor would be available for 200 KES per day, which is equivalent to five hours working. The OAF program loan is KES 15,000, including seeds, fertilizers, and storage bags for maize. The farm consists of three acres. One acre is used for planting maize and beans, the other one is providing Napier grass. Additionally, an eighth acre of desmodium has been planted for the dairy cow and about 20 stems of bananas are being grown on one eighth acre. The rest of the land is being used for growing various vegetables in a kitchen garden. The farmers wish to further increase milk production in the future. Additional land could be rent for KES 7,000 for two seasons. Extension officers from OAF and SAC visit the farm approximately once a month. The farmers attended trainings about dairy feeding and crop management three times in 2018. Due to the regular visits, upcoming problems are being discussed with the extension officers during their visits. In 2018, the farmers and their family produced food for the household and were able to sell milk to the cooperative, as well as bananas, maize, and beans on the market. They received 40 KES per liter of milk and had a female calve, which was passed on to another farmer, according to the concept of SAC. It can be easily noted that the available family labor time in this case is not a limiting factor. The option for off-farm income was not examined in the interviews and will therefore not be further treated in this thesis.

Table 6: Kakamega County typical smallholder dairy farm 2018 – TF18

Overview - typical farm household Kakamega 2018				Overview - spread of values in the sample					
				MIN	MAX	Frequency	Average	Median	Std. dev.
Land area available	acres	2,5		0,75	12	29	3,4	3	2,6
Labor time available	hours	4 500		1440	10710	29	4441	4320	1636
Labor time used	hours	1 403		*calculated value after estimation*					
OAF loan	KES	15 000		9000	41225	15	17868	15000	9368
1 dairy cow, estimated value	KES	70 000		25000	200000	27	77593	70000	46733
Farming income	***KES***	***48 950***		*calculated value after estimation*					
Activities									
Dairy	acres	1,125		0,25	4,125	28	1,04	1	0,8
Labor time	hours	780		720	3600	28	1607	1440	717
Variable cost	KES	35 000		9700	73400	26	33666	29957	18726
Production	liters	2 520		648	13200	26	3036	2520	2343
Household use	liters	1 100		209	3253	26	1008	661	711
Sales	KES	56 800		19680	440600	25	101487	78840	85571
Marginal return	*KES*	*21 800*		*calculated value after estimation*					
Maize-Beans IC season 1	acre	1		0,13	5,5	25	1,4	1	1,3
Labor time	hours	343		48	630	24	249	188	171
Variable cost	KES	11 500		450	150175	26	17711	8025	29170
Land preparation tractor	KES	1 600		600	6000	17	2816	3000	1512
Harvest maize	kg	1 400		360	3690	22	1459	1260	889
Harvest beans	kg	120		10	540	18	125	85	133
Household use maize	kg	700		270	2700	15	820	630	590
Household use beans	kg	50		20	270	12	82	70	67
Sales maize	KES	24 500		6000	115200	11	34691	31200	28848
Sales beans	KES	5 250		750	7200	10	3115	2700	1785
Marginal return	*KES*	*16 650*		*calculated value after estimation*					
Maize season 2	acres	0,5		0,25	2,5	10	0,73	0,5	0,6
Labor time	hours	220		73	864	5	359	274	278
Variable cost	KES	3 000		160	25500	6	4375	7193	8357
Harvest	kg	200		20	360	6	183	180	111
Household use	kg	100		*due to lack of explicit statements missing*					
Sales	KES	3 500		*due to lack of explicit statements missing*					
Marginal return	*KES*	*500*		*calculated value after estimation*					
Bananas	acres	0,125		0,25	1	6	0,42	0,25	0,28
Labor time	hours	60		*estimation of SAC officer*					
Sales	KES	10 000		1700	210600	13	20375	40679	54762
Marginal return	*KES*	*10 000*		*calculated value after estimation*					

4.3 Reference model LP application – “RM”

This section describes the data transfer of Table 6 to the GAMS software and the LP application. The reference model (“RM”) is being done for model validation and to identify if the typical farm household has potential inefficiencies that could be reduced.

The typical farm is being adopted before running the model. The maize-bean IC requires a specific treatment. While the crops share the land they grow on, some of the tasks are different, especially in labor time demand. Instead of summing up maize and beans, in the model the IC consists of two separate activities. This requires a constraint that the area of maize and beans must be equal in the solution. Another issue comes up for dairy production as the non-divisible cows require the model to become a mixed integer programming (MIP) model. Model results in an LP can take on various values and decimal numbers, if not pre-set in a different manner. Concerning crop production this is not that relevant, as it is possible to crop 0.7 acres of maize. It gets more finical regarding animals. As the farmer is not able to bring 0.7 dairy cow into production, the model needs a command to apply an integer function for the activity “dairy”. The maximum production for bananas is being set to 0.25 acres, as the situation about the market remained unclear after the interviews. It is the crop with the highest gross margin and would lead to a specialization on banana plantation in the LP, which appears unlikely and obviously is not part of farming strategies according to the interviews.

The farming income in TF18 did not consider the value of production that has been consumed by the household. As this poses a crucial factor for a smallholder farmer, it is being included in the LP application and enables a further aspect in the following analysis of the scenarios (*see section 5.3*). Therefore, the RM introduces a simplified method to include and assess the household consumption. According to the sample, representative amounts of maize, beans and milk consumption have been estimated. The quantities were being rated with market prices, as if the farmer could have sold the food at the market. Therefore maize, beans and milk can always be sold at the local market and there is no modelled production restriction. Table 7 shows the quantities and prices. For the RM and the scenarios in the following sections, the household consumption is already included in the calculatory farming income. A second comparison without considering it is also being carried out.

Table 7: Assumed household food consumption estimates

	kg	KES	Total
Maize	800	35	28 000
Beans	50	75	3 750
Milk	1100	40	44 000
SUM HH consumption		***KES***	***75 750***

The comparison of TF18 (equivalent to a typical real-world observation as it has been deduced from the sample) and the RM, representing the first LP application, is being presented in Table 8. The calculatory farming income after the LP is already covering the household consumption and shows a value of 140,813 KES. This is 13% higher than the determined calculatory farming income of TF18, which is 124,700 KES. As these values are calculatory, the farming income per se is more relevant for the farmer. Therefore, the value of TF18 (48,950 KES) and the RM (reducing household consumption from the calculatory income, resulting in 65,063 KES) are also compared. The percentual change is a possible plus of 33%. In the validation process, the activities and changes are being reconstructed. The reference model utilizes all the available land area for the optimal solution, increasing the activities maize-beans, maize in the second season and bananas. The result is reasonable, due to its high GM the banana acreage increase causes most of the change in the farming income. Labor hours are not a limiting factor, there is enough family labor available to cover the production increase. Shadow prices for land are being displayed. In April, an additional unit of land has a shadow price of 40,900 KES. In July prior to maize harvest, the shadow price for one acre of land is 8,000 KES. That means one additional acre of available land would increase the total farming income by 8,000 KES, as another activity would become enabled. These values are caused by the two season-pattern of the activities in the solution. Durable plantations, such as sugarcane or bananas, would show different effects. The shadow price illustrates the maximum value of a reasonable price for leasing additional land. Furthermore, Table 8 shows a value for labor productivity. This value does not consider opportunity costs for land, therefore it has a calculatory character. Reflecting total farming income and used family labor time, the TF18 had a value of 35 KES/hour. The amendments suggested by the reference model enable an increased labor productivity of 22%, from 35 to 42 KES per hour. Including household consumption in the consideration results in a smaller increase of 3%, from 89 KES/hour in TF18 to 92 KES/hour in the RM.

Table 8: Comparison of the typical farm TF18 with the reference model - RM

		TF18	RM	δ
Land area available	acres	2,5	2,5	
Labor time available	hours	4 500	4 500	
Labor time used	hours	1 403	1 534	**9%**
Farming income	KES	48 950	65 063	**33%**
Labor productivity	***KES/hour***	***35***	***42***	**22%**
Household consumption	KES	75 750	75 750	
Calculatory farming income	KES	124 700	140 813	**13%**
Calculatory productivity	***KES/hour***	***89***	***92***	**3%**
Activities				
Dairy	acres	1,125	1,125	
Cows	number	1	1	
Maize-Beans IC	acres	1	1,125	
Maize season 2	acres	0,5	0,563	
Bananas	acre	0,125	0,25	

4.4 Evaluation of three scenarios to increase the farming income

In the following section the RM is being further adapted and extended to enable an evaluation of three different scenarios to increase the household's farming income, compared to the RM.

4.4.1 Increasing the number of dairy cows – "SC1"

As TF18 did not rent additional land, the option has not been included in the RM so far. Given, the minimum household food consumption needed to be produced on the farm, there was no choice to procure food at the market. In SC1 these two options become available and enable an increased number of dairy cows. Feeding a second cow would potentially increase the land claim to 2.25 acres, which forces the farmer to procure staple foods at the market. Renting additional land allows to keep producing food for household consumption on the farm and/or increasing the dairy herd. Therefore, the model is being extended with the option of renting additional land for this and the other scenarios. Among the farmers in the sample, 43% stated to already rent land. The average price in the region is 7,000 KES for one year – compared to the shadow price mentioned in the RM (8,000 KES) it would be an economically reasonable decision to do so. According to an SAC officer, up to three acres of land would be easily available as for some people in the area, the financial aspect of leasing the land to someone is more important than the agricultural value (Wanyoni, 2021, s.p.).

As can be seen in Table 9, the available three acres appear in the optimal solution. Compared to the RM, plus 139% of the available family labor is being used. While still the maximum available time is not yet reached. Considering the farming income (223,125 KES) an increase of 243% is possible. The effect on labor productivity is being illustrated with a 44%-increase, from 42 to 61 KES/hour. Regarding the calculatory incomes including household consumption the effect is slightly different. The farming income increases by 112% to 298,875 KES. Due to a lot higher utilization of labor time, the labor productivity per hour even decreased about 11% to 82 KES/hour. Regarding the household consumption, the option to buy food at the market is available but is not part of the solution. The maize-beans IC is being performed to a smaller extent and even an excess production sold at the market. The optimal solution of SC1 increases the number of dairy cows to four. If more land would be available, it would appear in the solution until the labor time would be fully exhausted. In this scenario, the shadow price for an additional unit of land in June is 40,900 KES, in August it is 8,000 KES. That relates to activities that would become possible if more resources were available in the respective periods. The cow pens on the visited farms in the region were rather simple and did not cause large investment costs. Therefore, it should be considered that a housing facility for four cows needs to be more elaborate and organized than it must be for one cow. Overall, a simple increase of dairy animals is a rather obvious measure to increase the farming income of the farm.

Table 9: Scenario 1 – Increased amount of dairy cows

		SC1	RM	δ
Land area available	acres	5,5	2,5	**120%**
Labor time available	hours	4 500	4 500	
Labor time used	hours	3 663	1 534	**139%**
Farming income	KES	223 125	65 063	**243%**
Labor productivity	***KES/hour***	***61***	***42***	**44%**
Household consumption	KES	75 750	75 750	
Calculatory farming income	KES	298 875	140 813	**112%**
Calculatory productivity	***KES/hour***	***82***	***92***	**-11%**
Activities				
Dairy	acres	4,5	1,125	
Cows	number	4	1	
Maize-Beans IC	acres	0,75	1	
Maize season 2	acres	0,375	0,5	
Bananas	acres	0,25	0,25	

4.4.2 Intensifying the feeding ration – "SC2"

Most of the smallholder farmers in the region use Napier grass as main feed for their dairy cows. The amount of concentrate feeds and supplements depends much on available cash, the dairy management and the farmers' knowledge. The feeding rations and corresponding milk yields were not recorded in detail in terms of nutrient balances. Feed purchases were included in the VC. To create different intensities of dairy production, the farms in the sample have been used for an estimation of VC and corresponding milk yields. One farmer practiced on-farm silage making in addition to Napier grass feeding. As he stated his VC and data concerning silage making in the interview, his data is being used to demonstrate an alternative dairy production activity. Table 10 illustrates the solution of SC2, a farming income of 254,295 KES can be reached. This is an increase by 291%, compared to the RM. Labor productivity increases by 102%, from 42 to 86 KES/hour. Taking household consumption into account, the increase compared to the RM is 134% (330,045 KES), for labor productivity it is 21% from 92 to 111 KES/hour. The model resulted in a combination of Napier grass and silage feeding, the maize-beans intercrop is also being performed on 1.66 acres. For the farmer the suggestion of combining Napier and silage production could be an incentive to deal with different, more intensive feeding schemes, as the potential income in total is even higher than it was in SC1. As this optimal solution only recommends two cows and increases the maize-bean acreage, compared to SC1, less labor is being utilized. The shadow price for hired labor in August is 64 KES. An additional unit of land in June shows a shadow price of 42,670 KES.

Table 10: Scenario 2 – Intensified feeding ration

		SC2	RM	δ
Land area available	acres	5,5	2,5	**120%**
Labor time available	hours	4 500	4 500	
Labor time used	hours	2 974	1 534	**94%**
Farming income	KES	254 295	65 063	**291%**
Labor productivity	***KES/hour***	***86***	***42***	**102%**
Household consumption	KES	75 750	75 750	
Calculatory farming income	KES	330 045	140 813	**134%**
Calculatory productivity	***KES/hour***	***111***	***92***	**21%**
Activities				
Dairy napier cows	number	1	1	
Dairy silage cows	number	1	0	
Maize-Beans IC	acres	1,66	1	
Maize season 2	acres	0,06	0,5	
Bananas	acres	0,25	0,25	

4.4.3 Farmer cooperation – “SC3”

The database for this model farm is not the typical farm TF18 but the only larger scale dairy farm that has been visited in the study region. The information was limited to operational aspects. The investment costs and details about the organization’s background were not part of the interview.

The idea for this cooperation model is that farmers pool their labor time, farmland for feed production, and set up a large stable together for housing their dairy cows. Animal management, feed management and milk management would be handled and organized together. In this basic example for the smallholder farmers, they share all the tasks among each other, for example within a certain rotation concept. An important aspect is the level of mechanization on the farm if this project would become real. The farm manager mentioned annual expenses of KES 56,000 for electricity and another KES 50,000 for fueling the water pump. The interviewed smallholder farmers did not have these appliances and subsequently did not face expenses related to them. Water was either provided with simple wells at the farm or fetched from another place, milking was done manually, and the smallholder farmers did not have on-farm cooling facilities. Setting up a cooperation farm in one place and working on a large-scale level would probably make these infrastructural appliances necessary and the costs need to be considered. Overall, the cooperation would split the risk for each of the individual farmers and has the potential to make production more efficient as yields would be increasing and farmers would become more flexible in terms of labor time.

For this scenario, the idea was a cooperation of 10 farmers who share their 10 acres of land, and each farmer contributes 80 labor hours per month. The household consumption of food does not play a role in this model as the farm is specialized in milk production. Each of the farmers receives a part of the farming income. In addition to the basic Napier grass and silage production options that have already been described in SC2, intensified feeding with a combination of silage and concentrates is being introduced. It is characterized by less acreage needed and much higher VC, which is being compensated by a higher annual milk yield. The aspects that are not being displayed in the model are fixed costs and investment costs.

Table 11 shows the suggested implementation. The optimal solution after running the LP would be a specialization in the high intense production. Due to the programming aspect of integer and non-integer variables, Napier has been left for the non-integer option. Therefore, the rest of the available capacities is filled up with Napier grass production. The farming income divided by the 10 farmers results in 96,264 KES, which is an income increase of 48% while the real-time labor for each farmer decreases to 525 hours. In this case there is no calculatory household food consumption, as the farmers specialize in dairy and do not perform any subsistence food production. Compared to the farming income of the RM, the individual farmer's result denotes an increase by 48% to 96,264 KES while the labor input decreases by 66% to only 525 hours. While it must be assumed that the farmer needs to buy food for household consumption, the labor time savings would enable additional income possibilities. The time is available due to the higher labor productivity being shown in this scenario.

Table 11: Scenario 3 - Farmer cooperation

		SC3	RM	δ
Land area available	acres	10,0	2,5	**300%**
Labor time available	hours	9 600	4 500	
Labor time used	hours	5 250	1 534	**242%**
Farming income	KES	962 641	65 063	**1380%**
Labor productivity	***KES/hour***	***183***	***42***	**332%**
Per farmer				
Labor input	hours	525	1 534	-66%
Income per farmer	KES	96 264	65 063	48%
Activities				
Dairy Napier	cows	1,5	1,125	
Dairy Silage	cows	0,0	0	
Dairy High	cows	5,0	0	

5. Discussion

5.1 Applied methods

5.1.1 Sampling and data collection

As described in *section 3.3*, for statistical representativeness a certain sample size is needed. This could not be assumed for the survey carried out in this thesis. Sampling should also be done in a certain way to ensure the randomness of the interviewees. In this case, the choice of farmers visited was mainly influenced by the lady cooperating with SAC, who knew the farmers. Interpreting the entire examination more of a qualitative research perspective needs to be considered. Therefore, new insights could be gained through the survey results and the thesis outcome.

It has been challenging that the farmers rarely kept records. This made a detailed interview difficult in certain aspects, such as labor times, while in others, the farmers have a lot of data in mind very precisely, for example VC concerning dairy production.

The interview duration was rather long, while it must be highlighted that certain details that were intended in the questionnaire were left out completely, such as other farm animals than cattle. For repeating the survey, the questionnaire would need modification, while regarding the covered topics the duration would probably not reduce a lot.

Due to the small sample size, the research team consisting of the interviewer and the SAC group farmer, acting as guide and translator, was the same in all the interviews. This might have a beneficial effect, as the conditions for the farmers and the way of interviewing remained rather constant in the sample. Furthermore, the analysis was being done by the interviewer, which enables less risks for unclarity concerning handwriting or misinterpretation.

Some of the mentioned issues could have been tackled after carrying out a pre-test and allocating enough time for analyzing and improving the research tool. In this thesis project the pre-test unfortunately had to be canceled without replacement. In retrospect, the cancelation even highlights the importance of the pre-test as crucial tool for data collection and research tool evaluation.

5.1.2 Qualitative data analysis

The pertinence of the qualitative data and the additional information that was gained through the interviews revealed during data collection and in the course of the analysis. The focus on the qualitative aspect allows to get a broader understanding of the farmers' situation. For example, the dynamic developments in the sugarcane sector and the fact that farmers in Kakamega County are affected by the MSC issue that much has not been a focus topic primarily, it rather came up after witnessing the abandoned company facilities on site and listening to the farmers' experiences. That also created a higher awareness for the importance of the narrative aspect of some of the questions.

5.1.3 Typical farm and LP application

The data of the typical farm 2018 have been transformed to the LP application in the RM and the subsequent scenarios. An LP basically combines the activities with high gross margins with the available resources and allocates them in the most efficient way. As the model is rather small, this would also have been possible by performing a simple comparison. The advantage of the LP is for example, that resources like labor time can be allocated monthly and peaks and shortages identified easily. Labor time has been unlimitedly available in the present sample. For the activities it might have been interesting to extend the possibilities. The ones presented were based on what the farmers performed. Introducing a new activity would have been an option, for example for the second season crop as there was not even a choice.

Concerning the scenarios, simple ways that would easily be applicable for the smallholder farmers have been developed. SC1 and SC2 are theoretically possible for all the farmers in the sample. SC3 has been mainly influenced by the Smart Dairy concept and the data for the LP scenario originate from one of the two visited large farms. It has not been further evaluated, if the farmers in the sample would be interested in a farm cooperation concept like SC3 suggests. It would need an organization, the government, or a company to support the cooperation and the farmers' investment.

An LP enables a very detailed analysis regarding dairy production, e.g. by modeling nutritional requirements or environmental impacts, as already discussed in *section 2.3.2* (Kikuhara et al., 2009; Moraes et al., 2012). It would have been an interesting addition in this study to add details about concentrate feeds and nutritional requirements of the dairy cows. The data material and quality did not support such an elaborate application. The data utilized in the LP application was based on average values and estimations, according to the interview data.

5.2 Interview results

5.2.1 Female farmers

About 75% of the interviews have been conducted with women. As just being mentioned, the sample was mainly influenced by the SAC group farmer. Critics note that agricultural surveys often only focus on land ownership instead of talking to the people who do the work. The role and the influence of women and their comprehensive activities on farms, including their economic situation, should be better reflected. As argued in a KNBS report, only 7% of the agricultural extension efforts benefit women while they handle 80% of the food production in Kenya (KNBS, 2019b, p.4). Official data about the gender distribution is lacking as well as many other agriculture-related questions. Despite the importance of the agricultural sector in Kenya, the last agricultural census was carried out in 1963 (KNBS, 2019b, p.25).

5.2.2 Continuous cash and capital endowment

Hildebrand and Cabrera (2003) raised an important point regarding farm model creation. As seasonal cash flow as well as seasonal availability of food are important factors especially in the livelihood of a smallholder farmer, they suggest including a multi-period basis within a year into a model (Hildebrand & Cabrera, 2003, p.1). In the presented model, a monthly horizon was considered for labor hours and land resources. Configuring monthly cash flows as well as illustrating monthly yields could be an enrichment for the model. For this case, monthly milk sales would be a reasonable model amendment, if the challenge of detailed data procurement can be successfully performed. A strategy to obtain more detailed data could be accompanying the same farmers for a certain time and to collect data on repeated visits. Certainly, without keeping notes it is difficult for example to state details in February regarding past April.

Furthermore, the model did not cover capital endowments, which can be considered in general in LP applications (e.g. the capital endowment in Majeke et al., 2013). A certain cashflow could be assumed through the farmers' dairy income. For sure, cash is even more important the less capital a farmer has available. Despite in TF18 the couple runs their agricultural production as a full-time profession, a remarkable part of the farmers in the sample or at least their partners had income opportunities outside the farm. Another option that the farmers in the sample would use as a loan is the input procurement by OAF. In that context, the NGO support should be highlighted. OAF states that the profit impact of farmers working with them is an increase of 43% (Siegal, 2017, p.18.). The positive impact of the NGOs, in terms of support as well as guidance and education, is being mentioned by the farmers continuously. Especially in the chances and changes analysis and in *section 4.1.7* this becomes traceable.

5.2.3 Extension services and training

An often mentioned and highlighted topic in context with smallholder farmers is the importance of extension services. The farmers in the sample stated being visited regularly by governmental extension officers as well as from the NGOs. According to Manfre and Nordehn (2013), the traditional ways of accessing information include social networks like neighbors or extension agents, as farmers want to verify with another person before putting something new into practice. ICT can be a new option to distribute information and help to overcome the geographical, temporal and personnel barriers in a cost-effective way. Another advantage is the diversity of ways to deliver content – audio, visual and written media can reach various levels of literacy and education (Manfre & Nordehn, 2013, pp.3-7). The farmers in the sample almost concordantly answered that they would prefer face-to-face consultations to a multimedia alternative. Though, they stated various examples of useful ICT applications related to their farming activities (*see Table 5)*. They mention that they would try something new after watching a farmer presenting his farm project in a TV show. Another outstanding topic were SMS services. Farmers find it as a facilitation to be reminded to buy inputs or to start land preparation earlier.

5.2.4 Crop land and practices

The situation that revealed with the sugarcane issue in the study region is of a high interest. Some of the farmers still thought about going back to cane farming, despite the difficult conditions. The crop's historical meaning shall not be underestimated. For 71% of the farmers, dairy farming was rather new with less than five years of experiences on the farm. Unfortunately, the question if sugarcane has been the main activity before the dairy cow was not part of the interview. The region was strongly affected by MSC, and it can be assumed that dairy promotion among sugarcane-focused farmers has already been practiced twenty years ago. Mbagaya et al. (2004) did a study addressing the nutritional impact of dairy production in Mumias region, as malnutrition among children has been prevalent there. The affected children were especially these from families who practiced monoculture sugarcane farming. If they owned a dairy cow the families were able to increase their milk consumption and the children's nutritional status improved (Mbagaya et al., 2004, p.10). Another consequence of the intense sugarcane farming were soil depletion and erosion. That also reconnects to the farmers' statements in *Table 2* (*see section 4.1.2*), where they mentioned that the dairy cow and manure application increased soil fertility. In *Table 4* (*see section 4.1.6*) the farmers also mentioned that the NGOs focused on generating vegetable gardens for the families. Horticulture could also be an option creating GM as a second season crop. The importance of planting maize has already been highlighted in *section 4.1.7*. As ugali is the main staple food in the region, the large distribution of maize as crop is comprehensible. At the same time, the farmers complained that in the short rain season the weather is not favoring maize. More traditional crops, such as millet or sorghum, would be less sensitive to water scarcity but the farmers do not want to quit maize production as they will usually just eat it. This is different with sugarcane, as it is a cash crop, and the farmer needs the processing industry to be able to create an income. Sugarcane can also be used as a good example for the relation of international food markets. As long as the sector has been protected, the Kenyan sugar industry was flourishing. After opening the market, cheap sugar has been imported and the Kenyan smallholder-based sugar production did not success in being competitive (Kioko, 2015, s.p.). In a globalized world with open markets, this framework could be repeated with many other commodities. Mugambi et al. (2015) compared Kenya's milk production costs to other countries and concluded that Kenyan smallholders are not competitive on international markets (Mugambi et al., 2015, p.7897). Focusing on smallholder farm intensification it needs to be considered that this concept makes sense up to a certain point. An intensification to feed the regional population, create employment and raise the farmers' incomes has a positive impact on the employment and income situation in the region – a situation where a cheap product needs to be produced in an industrial way, just to feed an export market being dependent on world market prices is not a good perspective for Kenyan smallholder farmers. Kakamega's smallholder farmers are an important player due to their potential contribution to the development process. The MSC sugarcane story creates an awareness for the power that politics and governmental interventions can have. It is crucial to find the balance of how much incentive and support should be given and when it is a good time to let the market regulate certain aspects.

5.3 Model results

The scenarios and the model solutions of section 4.3 and 4.4 are being analyzed. Furthermore, productivity changes and respective income effects that have been revealed through model application are being discussed in the following section.

5.3.1 Scenario overview and income impact evaluation

In *section 4.3*, the household consumption aspect is being described. Therefore, two methods for scenario interpretation can be performed, one that considers household food consumption and one without. First, table 12 gives an overview and compares the results of the LP applications, being presented in terms of labor productivity and farming income.

Table 12: Productivity and income overview

		RM	SC1	SC2	SC3
Labor productivity	KES/hour	42	61	86	183
δ to RM in	%		45	105	336
Farming income	KES	65 063	223 125	254 295	96 264
δ to RM in	%		243	291	48

The highest farming income (254,295 KES) can be generated with SC2, SC3 has the lowest potential to increase the farming income for an individual farmer. Therefore, the income of SC2 is by 291% higher than in the RM, for SC1 it is 223,125 KES and can also be increased by 243%. In terms of labor productivity, SC3 has an advantage as it demands less labor time per farmer. The labor productivity is with 183 KES/hour by 336% higher than in the RM. For an on-farm implementation of any scenario, further investment, capital and running costs would have to be considered. The smallholders in the sample carry out dairy farming on a very basic level, their investments are manageable. SC3 would need much more financial assets, additional planning, and organization, therefore the implementation for individual smallholders is rather theoretical. The cooperation model can be a good option for farmers who have a solution for management, organization, and investment. Possibly an NGO or a private institution, like a dairy processing plant, could cooperate with farmer groups to enable these highly productive dairy farming units. As the farmers only use a certain amount of their labor time and land for the cooperation model, they could utilize the rest of their capacities for cash crops, household consumption production, or even an off-farm part-time employment instead. For a smallholder who wants to increase her or his income, SC1 or SC2 seem more favorable and predictable than SC3. For SC1, more labor time is needed as the number of cows is being increased more than in SC2. SC2 can generate a higher labor productivity, as the combination of two dairy cows with intensified feeding and the maize-beans intercrop enable a more efficient utilization of the farmer’s labor time. Overall, it should be considered that the productivity increase comes at a certain cost and the sales from increased production need to outweigh the investments and additional VC. Few of the farmers in the sample could not generate a positive GM from their dairy farming activities. The underlying reasons could not be assessed in detail, but one farmer mentioned fecundation problems with his dairy cow. He already faced a lot of AI and veterinary costs, while he does still not sell milk. Increasing household spending for the dairy animal instead of generating an income is not the optimum strategy for a poor household. Table 12 just displayed the farming incomes that could have been generated by selling the excess production. A certain amount of food had to be reserved for the HH consumption and therefore could not be sold. The farmer did not earn the value of these products. The calculatory farming incomes that include the value of the HH consumption are being presented in table 13 and enable a different perspective. As in SC3 the farmers do not produce food for their HHs, this scenario is not part of the comparison.

Table 13: Productivity and income overview, HH consumption included

		RM	SC1	SC2
Labor productivity considering HH consumption	KES/hour	92	82	111
δ to RM in	%		-11	21
Farming income considering HH consumption	KES	140 813	298 875	330 045
δ to RM in	%		112	134

While the farming incomes in SC1 and SC2 increase by 112% and 134%, the labor productivity in the RM has an advantage with 92 KES/hour compared to SC1. SC2 remains the scenario with the highest results, both for farming income (330,045 KES) and labor productivity (21 KES/hour). The suggestion of combining Napier grass feeding and silage production caused the best results for farmers in the analysis. Basically, this is what the NGO SAC recommends and focuses on in farmer trainings. Some further considerations regarding the analyzed scenarios are being employed in the subsequent sections.

5.3.2 <u>Household food consumption</u>

The applied method of including household food consumption has been very basic and simplified, assuming a certain amount of maize, beans, and milk. The estimated consumption quantities were being rated with market prices as used in the model. These prices can vary a lot in the course of a year and pose a potential difficulty in model applications. The prices stated by the farmers can therefore also vary a lot. The applied price estimations have been validated for reasonability by checking Kenyan market prices for Kakamega County (KNBS, 2018b, s.p.). For the consumption quantities, a similar check has been performed (KNBS, 2019c, 16). Especially for smallholder farmers, household food consumption is an important factor as subsistence is often their main goal and a farming income is just being generated if excess production to sell is available. Regarding the context of a farmer in SSA, the aspect of food security in terms of availability of food at the market and money to buy it play a significant role. Therefore, producing food on one's own and providing basic subsistence for the family has a different value than a model can tell. On the other hand, regarding climate change and crop production insecurities, a potential income can have a higher value than the harm induced by crop failure. Mellor (2017) emphasized, that a person with sufficient financial entitlements will always be better off in times of food crisis (Mellor, 2017, p.2). The crucial factor in that relation might rather be a person's income opportunities than the income source. For instance – if a smallholder farmer would leave the agricultural sector for a well-paid off-farm income option, even in times of food crisis he will be better off than with a low farming income.

5.3.3 Productivity increases and income effects

Economic transformation processes are accompanied by tremendous changes in an economy's work environment, as it is being pulled together in *section 2.2*. More options with higher income possibilities outside the agricultural sector become available once a certain point of economic development is reached. Until then, poor farmers, particularly in SSA, could benefit from higher incomes caused by productivity increases on their farms, for example as being examined by the implementation of SC2. Further increased productivity is in many cases related to a reduction of labor time. As family labor is almost abundantly available on the observed smallholder farms, the task coming with increased productivities in agricultural production will be where to occupy all these workers. As highlighted by SC3, labor productivity can reach a high level under the premise that large financial investments are a necessary precondition to do so. The County government's plan is, among others, to stimulate dairy production to improve the conditions in the entire value chain and subsequently, create new employment opportunities in the region (CGK, 2018a, p.76).

6. Conclusions

The goal of this thesis is to reveal challenges, chances, and plans of smallholder farmers in Kakamega County in western Kenya. An insight into the farmers’ conditions is being given and strategies to increase productivity on these farms are being evaluated. This is a relevant topic as productivity increases on smallholder farms are being highlighted as an important growth indicator in economic development theories. As poverty alleviation for these farmers is a prevalent issue, the context of increased productivity and farm income effects is being investigated. The research questions also concentrate on getting a comprehensive insight into the farmers’ economic situation and examinate what their drivers and challenging topics are.

A survey among 30 farmers in Kakamega County has been carried out. According to the gained data, a typical farm of the year 2018 has been selected. Due to various economic and food security related aspects, dairy farming is being promoted and the entire dairy value chain shall be fostered in the county. Sugarcane plantations have been a prevalent production strategy for smallholder farmers in the region. Changed market conditions in the sugarcane industry affected the farmers and diversification strategies have been stimulated. The smallholder farmers associate positive experiences with dairy farming (such as income generation, soil fertilization, food security) and want to increase their dairy businesses. With an LP application, three scenarios have been developed to increase productivity on this typical farm. The results of the three scenarios reveal possible income and productivity increases. Basically, the productivity increases in SC1 and SC2 can be reached without large investments. Specific trainings concerning feeding strategies and animal management can have relevant impacts. According to the explored data in the study, these trainings are already being offered by the NGOs. Maybe the on-farm implementation needs to be fostered more. As the government supports the famers by providing subsidized AI and most of the farmers make use of it, another option would be to subsidize inputs such as concentrate feeds as well, to increase the adoption rate.

With ongoing productivity increases in agriculture, due to the household structures and family labor availabilities, the gradually released workforce needs a labor market. In a successful economic development process, employment opportunities will be generated outside the agricultural production sector. Boosting the dairy value chain might induce the desired developments. Therefore, the political mission should be to enable and promote the concomitant growth and employment creation in related, non-agricultural sectors.

The surveyed farmers receive governmental and non-governmental support. This covers extension services as well as inputs, most of the farmers even received the dairy cow as a gift. A goal for the smallholder dairy farmers should be to become self-sufficient and economically independent, being accountable for investments. Topics for following studies could treat the future of Kakamega's dairy sector and the performance of the investigated smallholder farmers. Furthermore, the future of the sugarcane sector is a concomitant research field. The support, on the surveyed farms especially by the NGOs SAC and OAF, is an essential condition that the farmers rely on to run their businesses. Therefore, the temporal frame of these offers needs to be kept in mind as NGO projects normally have a termination date. The risk for the farmers to be left alone after the end of such a project exists. A suggestion is to connect governmental and non-governmental partners to make sure that essential and successful services can be continued. Another long-lasting option would be the focus on independence already during the project. Private institutions like banks or dairy companies could become project partners, in order that the conditions for a long-lasting cooperation have been set up already and the farmers are not being left alone after the NGO leaves.

What has been discussed in this thesis is the farmers' doubt or fear of trying new things, such as crops or different methods. Many of the farmers mentioned positive impacts that were caused by the NGO trainings and newly introduced methods and crops. This seems like a positive environment for further encouragement to try and develop new farming activities. The banana plantations, that help many of the farmers to increase their household incomes without being labor or capital intensive, are a good example. While, according to the sample, selling milk to the cooperative is always possible, a statement about the situation at the market for bananas could not be made. Possibly, if bananas are difficult to sell, an evaluation of value added by combining bananas and milk would be worth to be considered.

An aspect that should not be excluded is the environmental impact related to the suggested productivity increases. It raises the question, if dairy farming in systems like the described ones on TF18, in SC1, or SC2 are suitable in terms of the environment and greenhouse gas-emissions. Each cow is an emission source, fewer cows producing more efficiently could potentially be environmentally friendlier than a higher number of cows with a low milk production. Furthermore, the question of proper manure handling arises on the surveyed smallholder farms, as the animal housings were rather basic, many of them not even having a concrete floor. A scenario such as SC3 would at least in theory make the handling of excrements better manageable. This topic has not been evaluated in this thesis, a comparison of life-cycle analysis for the different scenarios would be necessary for a detailed judgement.

In countries with high living standards and incomes, agricultural production is an industrialized process to a certain part. Animal welfare and farm animals' living conditions are relevant topics in these countries. Certain governmental regulations need to be fulfilled and consumers also have an increasing interest and consciousness in the issue. In economies where people are facing hunger and poverty, the awareness for animal welfare is not that relevant. This relation seems to change, depending on the state of development. The consumption of animal products in the western world is becoming a more and more ethical topic, while animal husbandry in developing economies is basically seen as good option to induce structural transformation and to reduce poverty. For sure, the conditions for farm animals on smallholder farms are not comparable to industrial systems in western economies. Most of the smallholder farmers in the study had only one cow, but certain studies showed that nevertheless, the conditions for animals on smallholder farms are not automatically advantageous. Zero grazing is the preferred system for smallholder farmers to increase productivity, but the zero grazing units are not always respecting basic living conditions for the animals, such as comfortable resting areas. This can in turn be a productivity issue, as an animal with poor health conditions is a bad starting point for high productivity. The emphasis on productivity increases and intensification of agriculture in developing countries is important. In terms of future developments and learnings that have already been made, including animal welfare in the education and the intensification process is an important issue. Therefore, trainings should, already starting with the smallest farms, include and respect good living conditions for farm animals. The awareness should be initially created and strengthened to remain present during the whole process of economic development.

Increased agricultural productivity in SSA can have several positive impacts on food security and poverty reduction. If a farmer can elevate her or his income by up to almost 300%, as shown by the model results, with simple on-farm resource re-allocations and modified production strategies, these alterations should be supported to create long-lasting impacts. Sustainable achievements in terms of economic transformation are part of these farmers' visions. No matter if it's an SDG mentioning the end of hunger and poverty or Kenya's Vision 2030 stating the desire to becoming a newly industrializing middle-income country. For the individual farmer what matters are none of these statements, but long-lasting and sustainable economic transformation processes being enabled.

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List of abbreviations

ACET	African Center for Economic Transformation
AI	Artificial insemination
ATR	African Transformation Report
AU	The African Union
CAADP	Comprehensive Africa Agriculture Development Programme
CGIAR	Consultative Group for International Agricultural Research
CGK	County Government of Kakamega
e.g.	For example
FAO	Food and Agriculture Organization of the United Nations
GAMS	The General Algebraic Modeling System
GDP	Gross domestic product
GM	Gross margin
GR	Green Revolution
GoK	Government of Kenya
HH	Household
IC	Intercrop
ICT	Information and Communication Technologies
IFPRI	International Food Policy Research Institute
KDDC	Kakamega County Dairy Development Corporation
KES	Kenya Shilling
KNBS	Kenya National Bureau of Statistics
LP	Linear Programming
mio.	Million
MIP	Mixed Integer Programming
MoALF	Ministry of Agriculture, Livestock and Fisheries
MSC	Mumias Sugar Company
NGO	Non-governmental Organization
OAF	One Acre Fund
RM	Reference model
SAC	Send a Cow
SC1	Scenario 1, increasing the number of cows
SC2	Scenario 2, intensifying the feeding ration
SC3	Scenario 3, farmer cooperation
SDG	Sustainable Development Goal
SCARA	Strengthening Capacities for Agricultural Education, Research & Adoption in Kenya
SSA	Sub-Saharan Africa
TF18	Typical Smallholder Dairy Farm of Kakamega County 2018
UN	United Nations
USD	United States Dollar
VC	Variable Costs
WBG	The World Bank Group
WFP	World Food Programme

List of tables and figures

Appendix A: Questionnaire

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Questionnaire – Dairy Farm Intensification in Kakamega County

Dear respondent!
We are students from Egerton University and BOKU University (Vienna) and are cooperating for the international research project 'SCARA'. Please make sure to participate in this confidential survey only once you agreed to and signed the enclosed consent form. *Thank you for your cooperation and time!*

A Household identification		**Interview details**	
1. Sub-county		Household-ID	
2. Ward		Date	
3. Village		Begin time	
4. Farmer group		Enumerator	
5. Name of household head		**GPS location of homestead**	
6. Name of respondent (only if other than HHH)		Latitude (North)	
7. Relationship of respondent to HHH		Longitude (East)	
8. Distance to nearest market (walking minutes)		Altitude (m above sea level)	

B Household and overall farm composition — ***WHENEVER A "C" IS MENTIONED, PLEASE REFER TO THE RESPECTIVE CODE ABBREVIATIONS BELOW!!!***

	Gender	Age (years)	Education level (C.A)	Farming experience (years)	Thereof dairy exp. (years)	Main occupation (C.B)	Secondary occupation (C.B)
1. Household head							
2. Spouse							

3. How many people lived in your household and contributed to farm work from January to December 2018?

	Total	0-5	6-13	14-64	>65	Working on farm		Of persons aged 14-64 working on farm		
						Aged 6-13	Aged >65	Full-time	Part-time	No contribution
Male (M)										
Female (F)										

4. Please state the total average monthly working hours of people working on your farm in 2018 (family labor/hired labor):

JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP		OCT		NOV		DEC	
FL	HL	FL	HL	FL	HL	FL	HL	FL	HL	FL	HL	FL	HL	FL	HL	FL	HL	FL	HL	FL	HL	FL	HL

5. If you hired casual farm workers – what's the average daily wage (KES: __________) and daily working hours (HR: ________)?

6. If you employed permanent farm workers (No.___) – how many monthly working days (D: ___), daily working hours (HR: ____) and what monthly salary (KES: ____)?

Code A: 1= Primary School, 2= Secondary School, 3= Tertiary (College), 4= Vocational Training, 5= University
Code B: 1=Farming, 2=Self-employment, 3=Salaried employment, 4= Wage employment, 5=Pension, 6=Student

HH-ID: ___________ Enumerator: _________________ Page 2 of 8

7. Please state your net off-farm household income in 2018 (KES):		Salaries:	Wages:	Business income:
Pension:	Remittance:	In kind:	Government support:	Others – specify:

8. If you had access to credit in 2018 – please give details:

Who gave the credit to you?	Purpose	Interest rate	Credit period	Description of productivity increase or need for credit/investment

9. Please describe the major changes on your farm in the last five years? Which challenges did you face? Which conditions were favorable for your success?

10. Can you give an outlook for your farm in the next one to three years? Which challenges may come up, what are your plans and expectations?

C Farm land

1. Total acreage (acres):	2. Land dedicated to feed production (acres):
3. Dairy production system: □ Zero grazing □ Semi-zero grazing □ Open grazing	4. Land dedicated to pasture (acres):
5. Average price per acre to rent land? KES:_________ Availability? □ No □ Yes	6. Average price per acre to buy land? KES:_________ Availability: □ No □ Yes

7. Do you practice any of the following to prevent soil erosion? □ Zero-tillage □ Contour strip cropping □ Terracing □ Others (specify: ________________________)

8. Long rain season 2018	a) Land under cultivation (acres):	b) Thereof owned (acres):
c) Land rented in (acres):	d) Price per acre (KES/time span):	e) Land borrowed in (acres):

f) Fill the following table for the 5 main crops (in terms of acreage) that were cultivated in the long rain season 2018:

	Crop (C.C)	Acres	Intercropping (C.C+%)	Seeds				Fertilizer									Herbicides		Pesticides		Manure	
				Improved (kg)	P/ kg	Local (kg)	P/ kg	Type (C.F)	Q (kg/L)	P/ unit	Type (C.F)	Q (kg/L)	P/ unit	Type (C.F)	Q (kg/L)	P/ unit	Q (kg/L)	P/ unit	Q (kg/L)	P/ unit	Q (kg)	P/kg
1																						
2																						
3																						
4																						
5																						

HH-ID: ___________ Enumerator: _________________ Page 3 of 8

	Crop residues Y/N	Irrigation Y/N	Soil fertility (C.D.)	Soil slope (C.E.)	Land preparation				Planting			Weeding I			Weeding II			Fertilizer application		
					FL	HL	When	Cost	FL	HL	When	FL	HL	When	FL	HL	When	FL	HL	When
1																				
2																				
3																				
4																				
5																				

	Herbicide/pesticide application			Harvesting			Threshing				Other activities				Crop rotation (C.C./C.G.)					
															2015		2016		2017	
	FL	HL	When	FL	HL	When	FL	HL	When	Cost	FL	HL	When	Cost	LR	SR	LR	SR	LR	SR
1																				
2																				
3																				
4																				
5																				

9. Short rain season 2018 g) Land under cultivation (acres): h) Thereof owned (acres):

i) Land rented in (acres): j) Price per acre (KES): k) Land borrowed in (acres):

l) Fill the following table for the 5 main crops (in terms of acreage) that were cultivated in the short rain season 2018:

	Crop (C.C)	Acres	Intercropping (C.C+%)	Seeds				Fertilizer									Herbicides		Pesticides		Manure	
				Improved (kg)	P/ kg	Local (kg)	P/ kg	Type (C.F)	Q (kg/L)	P/ unit	Type (C.F)	Q (kg/L)	P/ unit	Type (C.F)	Q (kg/L)	P/ unit	Q (kg/L)	P/ unit	Q (kg/L)	P/ unit	Q (kg)	P/ kg
1																						
2																						
3																						
4																						
5																						

Code C: 1= Maize, 2= Common bean, 3= Soybean, 4= Groundnut, 5= Sorghum, 6= Millet, 7= Sesame, 8= Cassava, 9= Sweet potato, 10= other crops, 11= Kales, 12= Cabbage, 13= Tomato, 14= other local vegetables, 15= Banana, 16= Sugar cane, 17= Fruit trees, 18= other trees
Code D: 1= Good, 2= Medium, 3= Low
Code E: 1= Gentle slope (flat), 2= Medium, 3= Steep slope
Code F: 1= DAP, 2= CAN, 3= Urea, 4= NPK 17:17:17, 5= NPK 23:23:0, 6= others (specify: ____________)
Code G: 1= Napier grass, 2= Lablab, 3= Clover, 4= Vetch, 5= Alfalfa, 6= Sesbania, 7= Desmodium, 8= Fodder maize, 9= Caliandra, 10= others (specify: ____________)
P= Price, Q= Quantity, FL= Family labor, HL= Hired labor, state FL/HL in days (if in hours tick □), "When" – respective month(s), LR= long rain season, SR= short rain season
Other land preparation cost (KES) – oxen, tractor. Other threshing cost (KES) – storage chemicals. Crop rotation: crops on that plot in the last 6 seasons (put "F" for fallow)

HH-ID: ___________ Enumerator: _________________ Page 4 of 8

	Crop residues Y/N	Irrigation Y/N	Soil fertility (C.D.)	Soil slope (C.E.)	Land preparation				Planting			Weeding I			Weeding II			Fertilizer application		
					FL	HL	When	Cost	FL	HL	When	FL	HL	When	FL	HL	When	FL	HL	When
1																				
2																				
3																				
4																				
5																				

	Herbicide/pesticide application			Harvesting			Threshing				Other activities				Crop rotation (C.C./C.G.)					
															2015		2016		2017	
	FL	HL	When	FL	HL	When	FL	HL	When	Cost	FL	HL	When	Cost	LR	SR	LR	SR	LR	SR
1																				
2																				
3																				
4																				
5																				

9. Output (crops)

Crop (C.C)	Dry/ Fresh	Harvested quantity LR (kg)	Harvested quantity SR (kg)	Total quantity (kg)	HH con-sumption (kg)	Fed to livestock (kg)	Kept as seeds (kg)	Still in store (kg)	Donated (kg)	Losses (kg)	Sold (kg)	Price per kg (KES)	Average market price (KES)

10. Fodder crops (list all)

	Crop (C.E)	Acres	If planted in 2018: Seeds				Fertilizer									Herbicides		Pesticides		Manure	
			Improved (kg)	P/ kg	Local (kg)	P/ kg	Type (C. F)	Q (kg/L)	P/ unit	Type (C.F)	Q (kg/L)	P/ unit	Type (C.F)	Q (kg/L)	P/ unit	Q (kg/L)	P/ unit	Q (kg/L)	P/ unit	Q (kg)	P/kg
1																					
2																					
3																					
4																					

	Soil fertility (C.D.)	Soil slope (C.E.)	If planted in 2018: Land preparation				If planted in 2018: Planting			Weeding I			Weeding II			Fertilizer application		
			FL	HL	When	Cost	FL	HL	When	FL	HL	When	FL	HL	When	FL	HL	When
1																		
2																		
3																		
4																		

	Herbicide/pesticide application			Harvesting			Fodder conservation (Hay, Silage, ...)				Other activities				Crop rotation (C.C./C.G.)					
															2015		2016		2017	
	FL	HL	When	FL	HL	When	FL	HL	When	Cost	FL	HL	When	Cost	LR	SR	LR	SR	LR	SR
1																				
2																				
3																				
4																				

11. Output (fodder crops)

Crops (C.G/I)	Dry/Fresh	Total harvested quantity (C.H)	Quantity fed to livestock (C.H)	Still in store (C.H)	Donated (C.H)	Losses (C.H.)	Sold (C.H)	Price per unit (KES)	Purchased (kg)	Price per unit (KES)	Average market price (KES)

Code C: 1= Maize, 2= Common bean, 3= Soybean, 4= Groundnut, 5= Sorghum, 6= Millet, 7= Sesame, 8= Cassava, 9= Sweet potato, 10= other crops, 11= Kales, 12= Cabbage, 13= Tomato, 14= other local vegetables, 15= Banana, 16= Sugar cane, 17= Fruit trees, 18= other trees
Code D: 1= Good, 2= Medium, 3= Low
Code E: 1= Gentle slope (flat), 2= Medium, 3= Steep slope
Code F: 1= DAP, 2= CAN, 3= Urea, 4= NPK 17:17:17, 5= NPK 23:23:0, 6= others (specify: _____________)
Code G: 1= Napier grass, 2= Lablab, 3= Clover, 4= Vetch, 5= Alfalfa, 6= Sesbania, 7= Desmodium, 8= Fodder maize, 9= Caliandra, 10= others (specify: ______________)
Code H: 1= Kg, 2= Tons, 3= Bales, 4= Handcart, 5= Oxcart, 6= Wheelbarrow load, 7= Pick-up, 8= Bags, 9= Headload
Code I: 1= maize stover, 2= potatoe vines, 3= sugarcane cuttings, 4= banana suckers/leaves, 5= others (specify: ________________)

D Livestock	1.1.2018	Average value	Born	Received as gift/dowry	Received from government	Given away	Died	Bought	Price (KES)	Sold	Price (KES)	31.12.2018
Pure-bred cows												
Cross-bred cows												
Local cows												
Pure-bred heifers												
Cross-bred heifers												
Local heifers												
Pure-bred bulls												
Cross-bred bulls												
Local bulls												
Pure-bred steers												
Cross-bred steers												
Local steers												
Pure-bred calves												
Cross-bred calves												
Local calves												
Sheep												
Goats												
Donkeys												
Pigs												
Chicken												
Other poultry												

E Dairy

1. Did you carry out any of the following management practices in 2018 – if yes, please define the respective cost (KES)

Deworming:	Vaccinations:	Tick control:	Curative treatments:	Milking salve/Jelly:
Teat disinfect:	AI services:	Bull services:	Dehorning:	Technical support:

2. How many of your cows were lactating in 2018?

3. Milk production (liters)	Months	Total milk production (per milking)	HH con-sumption	Given to calves	Given out	Sales	Price (KES per liter)	Main buyer 1 (C.J)	Main buyer 2	Main buyer 3	Payme nt (C.K)	Avg. price
PEAK production months – **Morning**												
PEAK production months – **Evening**												
LOW production months – **Morning**												
LOW production months – **Evening**												
NORMAL production months – **Morning**												
NORMAL production months - **Evening**												

4. Dairy farm machinery	Q	Average price	Cost last year	Item	Q	Average price	Cost last year	Item	Q	Average price	Cost last year
Zero grazing unit				Milking churn				Calf pen			
Feed store				Feed mixer				AI-Kits			
Paddocking/fencing				Milking buckets				Deworming-Kits			
Milking parlor				Milking machine				Feeding troughs			
Water tank				Chaff cutter				Watering troughs			

5. Do you practice any form of value addition in milk products or other services, derived from cattle?

Product (Code L)	FL (days/hours)	HL (days/hours)	When	Units	HH consumption	Quantity sold	Price

6. Commercial feeds

Product (Code M)	Quantity (kg)	Price per kg (KES)	Transport/handling cost	Place of purchase (Code N)	Payment (Code K)

7. Please state the average feed ration for your dairy cows in the respective production months

	Fodder (C.G)	Dry/Fresh	Quantity (C.H)	Fodder (C.G)	Dry/Fresh	Quantity (C.H)	Commercial feed (C.M)	Quantity (C.H)	Commercial feed (C.M)	Quantity (C.H)
Low production										
Average production										
High production										

8. Dairy farm labor – please fill in the table (hired labor – please state P for permanent, C for casual worker)

Activity	Hours		FL	HL	Activity	Hours		FL	HL
	Daily	Weekly				Daily	Weekly		
Feeding					Cleaning				
Grazing					Fodder production				
Milking					Spraying				
Others (specify_____) When?					Others (specify: _________) When?				

9. Other variable costs	Electricity:	Water:	Others (specify: ___________)

Code J: 1= Cooperative society, 2= K.C.C., 3= Private processor, 4= private trader, 5= Hawker/informal trader, 6= Institutions/hotels/schools, 6= neighbors/consumers, 7= others (specify: ___)
Code K: 1= Cash on spot, 2= Cash weekly, 3= Cash at end of month, 4= Check-off (cooperative)
Code L: 1= Fermentation, 2= Yoghurt, 3= Manure, 4= Bull services, 5= others (specify: _______________)
Code M: 1= Dairy meal, 2= Maize bran, 3= Wheat bran, 4= Mineral supplement, 5= Concentrates, 6= Homemade ration, 7= Young stock pencils, 8= Others (specify: _______________)
Code N: 1= Agrovet, 2= Dairy cooperative, 3= NGO, 4= others (specify: _______________)

F Institutional factors and Extension services

1. How many input dealers (dairy, crops) are you familiar with? Are there any benefits for you?
2. What's the distance (walking minutes) to your next input dealer (dairy, crops)?
3. How many friends and relatives do you have, who let you graze your animals or cut fodder from their land without paying?
4. How many dairy/crop production and marketing-related groups are you and your spouse members of?
5. Did you benefit of any dairy intervention program (government, NGOs, new cooperatives) in the last 5 years? □ No □ Yes – if Yes: HOW? □ Market access
   □ Received an animal | □ Subsidized AI | □ Access to vet | □ Access to inputs | □ Contract marketing arrangements | □ Others – specify:
6. How many times did you have contact with an extension officer in 2018?
   Government officer: | Private officer: | NGO: | Others – specify:
7. Which topics were discussed? | □ Fertilizer use | □ Improved seed use | □ Crop management | □ Manure use
   □ Land use practices | □ Livestock management | □ Fodder management | □ Feeding livestock | □ Calf rearing | □ Others – specify:
8. How often were farmer trainings, farmer field schools, field days, demonstrations or other educational events organized in your area?
   □ Never | □ Once | □ Twice | □ Three times | □ Every month | □ More than that
9. Did you attend those events in 2018? | □ Never | □ Once | □ Twice | □ Three times | □ More than that
10. If not – why didn't you attend those events? Specify:
11. Did you ever change your agricultural practices after consulting an extension officer or training events (like in 9.)? □ No □ Yes: specify how, why?
12. What are your main sources of information about agricultural issues?
    □ Farmer group | □ Family/neighbors | □ Cooperative | □ Government extension service | □ Private extension service | □ NGO | □ Media
13. Do you have access to… | □ Smartphone | □ Mobile phone | □ Computer | □ TV | □ Radio
14. Do you use the following media for getting information about…

	Weather	Market prices	Crop management	Livestock management	Dairy specific topics	Farm mechanization	Increasing farming income
Radio							
TV							
SMS service							
Internet/Websites							
E-Mail							
Smartphone applications							
Others – specify:							

15. Did you ever change your agricultural practices after consulting one of the above mentioned (in 16.)? □ No □ Yes – specify how (able to save production cost, labor time, what's your advantage?):
16. If you use new media – how high are your annual costs (KES) for using them (asset cost, monthly cost, phone costs…)?
17. Do you see advantages in (□) new technology extension services or do you prefer (□) face-to-face settings (farm visits, field schools)? Please specify, why:
18. End time of the interview:

Thank you for your cooperation and time!!!

Appendix B: Consent form

Consent form

PART A: Project Information Household-ID:________________

I am __________________________ (name of enumerator) and I work with SCARA Project (a cooperation of Egerton University and BOKU University in Vienna) as an enumerator on this study. SCARA means 'Strengthening Capacities for Agricultural Education, Research & Adoption in Kenya' and works on topics related to water for food, with a focus being use of Information and Communication Technology (ICT) for efficient agricultural production. The SCARA Project also supports students in sharing knowledge on international level and cooperating in research projects. The aim of this study is to gain an insight into changes of land use practices caused by the intensification of dairy farming in Kakamega County.

I will take time to explain more about the study, please stop me whenever you need clarifications or to clarify meanings of words that you don't understand.

This exercise will involve your participation in this survey. We will ask questions about your household, crop and dairy production and the management and future planning of your enterprise.

The information we collect from this evaluation will be kept confidential. Any information about you will have a number instead of your name. Only the researchers will know your number and we will lock that information securely. It will not be shared with or given to anyone except the researchers in this project. The knowledge that we get from doing this study will be used to improve project activities. Confidential information will not be shared. Your participation in this study is purely voluntary. There is no financial compensation for your participation in this study. However, it is our hope that the knowledge gained from your participation in the study will benefit the whole community.

The data you share in the survey may be used in academic papers, policy papers, news articles or similar formats; in other media that we may produce such as spoken presentations and in an archive of the project.

If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. Before you decide, you can talk to anyone you feel comfortable with about the evaluation. If you wish to know more about this study or SCARA project, please contact:
Dr. Raphael M. Gacheiya, Utafiti Hall 3rd Floor, Suite 339, Egerton University. P.O. Box 536-20115. Tel: +254 720 477 709 (Co-Principal Investigator)

Do you have any questions?

May I begin the interview now?

PART B: Certificate of Consent

I have read the foregoing information, or it has been read to me. I have had the opportunity to ask questions about it and any questions that I have asked have been answered to my satisfaction. I consent voluntarily to participate as a participant in this evaluation exercise.

Signature of Interviewee: ____________________________ Date: ________________