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Dynamic System Evaluation of Fluctuating Processor Raw Material on Value Chain Financial Sustainability

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Abstract

As the global population grows, food self-sufficiency in developing countries becomes increasingly important and difficult, while the climate change threat strengthens (FAO, 2023). Due to variables such as weather, agricultural production remains volatile, providing processors with an inconsistent supply of raw materials, making it difficult to operate at a reliable and sustainable utilisation and supply food consistently and competitively in the global market. The processors' performance affects the entire value chain's financial sustainability as entire value chains compete and not individual nodes (Christopher and Rutherford, 2004).

This project aims to evaluate the impact of a change in available raw material volume at the processing node on the total value chain's financial sustainability. The project's goal includes illustrating and measuring the effect of seed availability, as well as determining the ideal (based on an optimisation model) amount of seed to be processed for maximum value chain financial sustainability. This is done with a system dynamic model that represents the Tanzanian sunflower value chain, including producers, traders and processors and measures its financial sustainability with the net income indicator.

The executed approach was developed from a literature review of value chain analysis to quantify and improve sustainability, which yielded that food supply chains, like the Tanzanian sunflower value chain, are best approached as a complex adaptive system (Higgins et al., 2010), which are widely analysed with simulation modelling (Alony and Munoz, 2007; Hosseini et al., 2019). System dynamics is a simulation modelling technique that can understand and capture the entire value chain system, including the complexities and dynamics (Özbayrak et al., 2007; Rebs et al., 2019). It quantifies the impact of the interactions and develops a time-dependent simulation of the nodes in a value chain (Georgiadis et al., 2005; Muflikh et al., 2021).

A system dynamic model was developed for the Tanzanian sunflower value chain as proposed by Sterman (2000a). First, the problem and its background were discussed and defined. Then the dynamic hypothesis with the causal loop diagram was developed. The main dynamic hypothesis assumed that the higher the local available seed supply, the lower the overhead costs per ton of seed processed, increasing the seed demand, providing seed producers with a reliable seed market, and increasing the seed price and production. After the causal loop development, the model with the mathematical formulation was compiled in AnyLogic, representing the Tanzanian sunflower value chain from 2012 to 2023. Finally, the model was verified and validated, with the boundary adequacy test, dimensional consistency, historic behaviour reproductivity test, structural behaviour, logical behaviour and extreme condition tests, of which the most important test was to ensure that the model replicated the historic industry trends (historic behaviour reproductivity test). The model development process was executed in an iterative process of going back and forth between the problem dynamic hypothesis, causal loop diagram, mathematical formulation and validation and verification until the model represented the real Tanzanian sunflower value chain system accurately.

After developing a reliable model, the model was adjusted to represent the future ten years (2022 to 2032) of the Tanzanian sunflower value chain to develop an understanding and possible representation of the future of the industry. The model recorded prices, costs, volumes, gross margins and net income for each node of the value chain for each month over a ten-year time period, and was analysed through the total value chain net income over the total ten years.

The analysed scenarios included a decrease and increase in sunflower seed availability (by 10% to 50%), a change in sunflower seed sources (local and imported seed) and an optimisation model that maximised the sunflower value chain and processor net income.

The decrease in seed availability had a negative impact on the entire value chain net income, with the processing node realising the largest loss. The impact was higher than the loss in volume because of the efficiency losses of producers and processors (due to higher overhead costs per ton) and the loss in the seed production area (a decline in processor profitability, decreased the seed demand, which decreased the seed-producing area). While an increase in volume yielded a smaller impact than the simulated volume increase. This was due to the price drop resulting from the seed volume increase, as well as processor efficiency gains having achieved their maximum once the processing capacity was reached. This meant that the impact of the increasing seed supply was lower than the impact of the decreasing seed supply for the same percentage of seed volume changes. The decreased seed scenario quantified the cost and losses of limited seed availability to determine the amount that can be invested in the value chain to prevent limited and volatile seed availability. Similarly, the increased seed scenario quantified the potential gain. Furthermore, the model identified the break-even point for the value chain to become financially unsustainable (when the total value chain net income becomes negative), which can assist in risk mitigation to manage the value chain and avoid the situation.

When analysing the scenario where seeds can be imported versus where seeds cannot be imported, a positive consequence of importing seeds was identified. The results were explained by the fact that the processor's utilisation increased (as the lacking seeds were imported), increasing seed procurement and providing a more secure market for seed producers, which in return increased local seed production. The advantage of importing seed (at the base model) was found to be almost equal to the net income advantage of processing an additional 10% of local seed. However, before promoting seed imports, the situation should be further investigated to ensure that the local sunflower seed producers are not negatively impacted by the imported seed.

After understanding the impact that different seed availability levels and sources have on the entire value chain's financial sustainability, an optimisation scenario was run to determine the ideal amount of seed to be bought and processed by processors to maximise the net income of the entire value chain, as well as maximise processor net income. By finding the ideal amount of seed to be processed, the relationships and trade-offs between price, cost and volume were determined to understand when an increase in seed volumes is more beneficial, versus an increase or decrease in prices and costs. This assists in identifying the required interventions to increase local processing and uplift the entire Tanzanian sunflower value chain. The optimisation results for the value chain and processing node were very similar, implying that uplifting the processor node's financial sustainability may improve the total value chain's financial sustainability. However, the ideal seed processing volumes were below the current processing volumes, thus indicating that the value chain would not perform at its optimum financial sustainability by processing more volumes and that increasing the local seed production will not solve the problem on its own. This emphasises the importance of a combination of interventions representing the entire value chain and refraining from changing one aspect in isolation (like increasing seed availability). Furthermore, this phenomenon is unique given the 2022 global oilseed situation where oil prices sky-rocketed due to the Covid-19 pandemic and the Russia-Ukraine war.

The system dynamic model represented the Tanzanian sunflower value chain accurately and contributed scientifically by allowing a range of scenarios to be simulated. The scenarios reported interesting indirect consequences and impacts on the value chain (that may otherwise have been missed) and illustrated how the model could be used to quantify the financial impact of a variety of different scenarios to analyse if interventions are beneficial for the entire value chain system, and quantify the impact on the financial sustainability of the value chain. The model integrated financial sustainability (net income per node) and system dynamics to capture the current state of the value chain. The developed model's results can inform decision-making to increase the sustainability of the entire Tanzanian sunflower value chain, and the financial health of all stakeholders. It assists in gaining insight into managing different raw material availability disruptions (increasing and decreasing seed availability). Furthermore, a significant scientific contribution was to optimise the entire value chain to maximise the total value chain net income by determining the ideal amount of seed to be processed.

However, as with most research, the model can be further improved to refine the results even further and incorporate different performance indicators (like environmental and governance) which may widen the reach of the results. As well as run more scenarios to strengthen the arguments of the results. A range of further research is possible, emphasising the model's relevance, agility and scientific contribution to investigate different scenarios and topics of the Tanzanian sunflower value chain.

Keywords: value chain, system dynamics, financial sustainability, optimisation

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Introduction

Tanzania is the largest sunflower seed producer in Africa (FAOSTAT, 2022), however, due to volatile variables (like weather conditions and production practices), the local sunflower seed production can fluctuate significantly from one year to the next, making it difficult for seed processors to operate at a reliable and sustainable utilisation. This project aims to quantify seed variability's impact on the entire value chain's financial sustainability (producers, processors and traders). The introduction provides an overview of the problem and the approach to solving the stated problem in terms of the research design and methodology. Some literature is discussed around the problem and solution methodology and the expected contribution is defined.

1.1 Background

A basic agricultural value chain consists of the nodes illustrated in Figure 1.1. Multiple inputs are used to produce agricultural raw materials. The raw materials are traded, which can be sourced locally or imported, and delivered to processing facilities. The processors convert the raw material into products which are traded (sourced locally or imported) and sold to consumers.

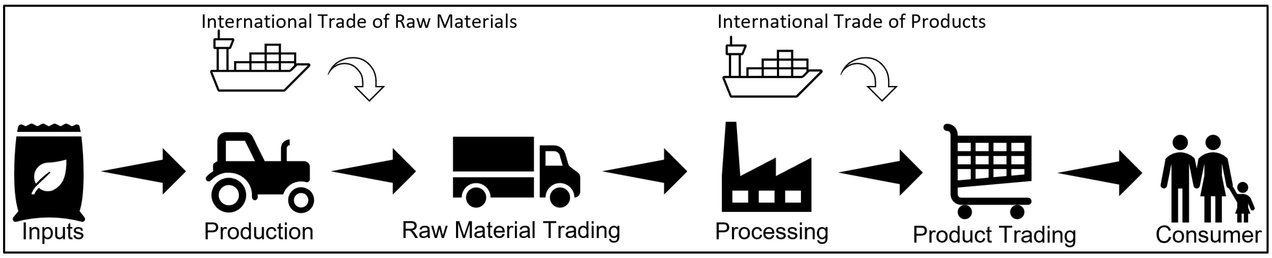

Figure 1.1: Simplified Agricultural Value Chain

Source: (BFAP, 2022; Van der Vorst et al., 2007)

With climate change becoming more pertinent, agriculture production is growing increasingly important to the earth's environment, and the environment has an increasing impact on agriculture production due to weather changes impacting harvests (FAO, 2023). While as the population grows, the need to increase agricultural products to ensure food security becomes increasingly important. In 2017, the Food and Agriculture Organization of the United Nations (2017) projected that agricultural outputs need to increase by almost 50% by 2050, with sub-Saharan Africa (including Tanzania) and South Asia required to double their production (FAO, 2023).

Thus, agriculture is challenged on the demand and supply side, and its ability to meet the growing food demand sustainably is a crucial question (FAO, 2023). Given this challenge, it is important to develop local production and processing to make developing countries, like Tanzania, self-sufficient and sustainable in raw materials and products.

Like many other African countries, Tanzania exports most of its raw material, and imports processed products at a higher price. Figure 1.2 illustrates the historic volumes traded of different agriculture and food products in Tanzania. Generally, highly processed goods are imported, while unprocessed and low-processed goods are exported. Processed goods go through value addition, converting them into a different, more desirable, high-value product. This requires further inputs and employment that provides an income for more individuals and their dependents in the country.

Furthermore, locally processed goods should in principle be cheaper as no international transport costs, handling fees, and potential import tariffs (not always applicable) are required to bring the product to market (USAID, 2008). However, globalisation enables countries to operate in markets worldwide, resulting in developing countries competing internationally with established and highly efficient value chains of developed countries. This makes it sometimes difficult for the local production and processing of developing countries to compete with imported products, as well as compete in potential export markets, and in becoming self-sufficient (Trienekens, 2011).

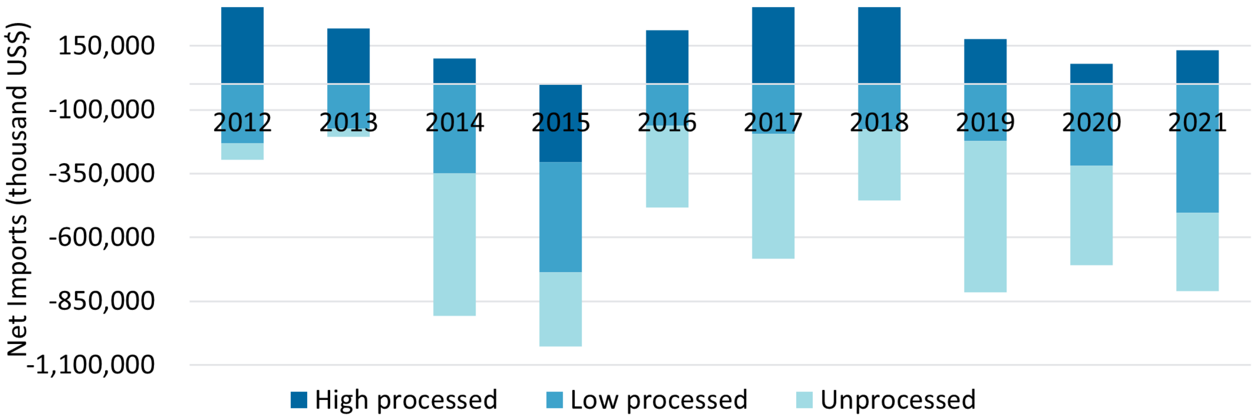

Figure 1.2: Tanzania Exports of Agriculture and Food Products

Source: (ITC Trade Map, 2022)

Due to Tanzania's high edible oil imports (ITC Trade Map, 2022), it has a great need and potential to process the domestically produced sunflower seed locally and replace oil imports, and even export products, like sunflower cake. However, due to globalisation, Tanzania competes with highly efficient and effective value chains for the production of sunflower seed and edible oil (like palm oil). But, by exporting the raw material and not adding value themselves, Tanzania is losing potential gross domestic product contribution, job creation, and social upliftment. Hence, it is important to develop an understanding of how competitive and sustainable the local Tanzanian sunflower industry is and why limited local processing occurs (BFAP, 2022).

The increase in population and food demand, together with the growing economy, creates great potential for local processing beyond the farm gate in Tanzania, yet limited investment is being seen (BFAP, 2022). According to BFAP (2022) and Trienekens (2011), access to raw materials with a reliable supply of utilities, specifically water, electricity and infrastructure, are the major constraining processing factors in developing countries. Raw material supply has been the focal point of many projects, with research being conducted to increase raw material volumes with production improvement techniques like hybrid seed use, fertiliser use, the use of mechanisation, and crop rotation. However, access to raw materials is still problematic due to insufficient and volatile supply. The raw material supply is always fluctuating due to agricultural raw materials being natural products and subject to energy and water supply, and climate impacts (Bjornlund et al., 2020; Krejci and Beamon, 2012), as illustrated in Figure 1.3 where 2021 sunflower seed production drastically declined due to drought.

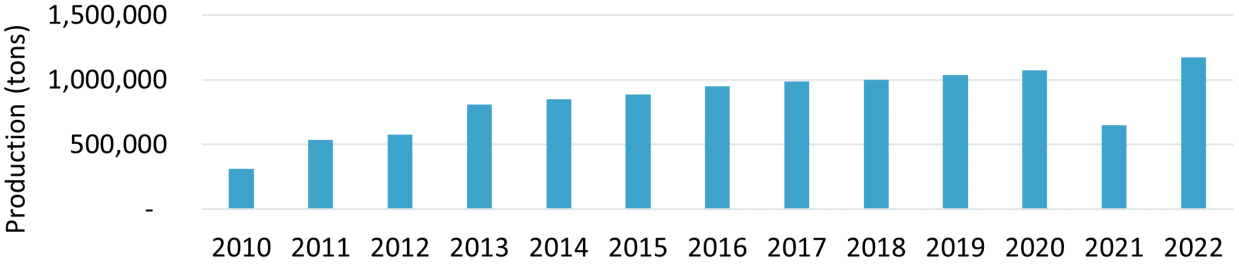

Figure 1.3: Tanzania Sunflower Production

Source: (BFAP, 2022; FAOSTAT, 2022)

The limited and volatile raw material supply has negative implications for the financial health of the processors, who are dependent on the raw material to operate and generate profit (Adeyemi and Olufemi, 2016). If limited raw material is available for processors, their utilisation drops, increasing the fixed overhead costs per ton of raw material processed (as the fixed overhead costs need to be incurred irrespective of the volumes processed). If the utilisation drops below a specific break-even point, the costs will offset the revenue, resulting in a loss, and making it infeasible for processors to continue with their operations (Afroz and Kumar Roy, 1976).

If the processors become financially unsustainable, the entire value chain (illustrated in Figure 1.1) is impacted because supply chains compete, and not just single nodes (Christopher and Rutherford, 2004). If processors become financially unsustainable (realise a loss), possible consequences may be that local sunflower seed producers do not have a local market off-take and need to compete in the international market, where developing countries are often uncompetitive due to traditional, inefficient production practices (Juraev, 2017). Furthermore, the country would have to be logistically geared to export the raw materials at a competitive transport cost. Additionally, if the final product is not produced locally, it needs to be imported to supply the in-country demand, which may be more expensive than locally produced goods due to transport costs and import tariffs (USAID, 2008), impacting end-consumers and food inflation.

Hence, the health and financial sustainability of processors is crucial for the entire Tanzanian sunflower value chain and its individual nodes, and assists in creating a resilient supply chain, which has gained increasing importance for risk mitigation (Christopher and Rutherford, 2004). The goal of this project is to quantify these impacts of limited raw material availability on the total value chain financial sustainability.

1.2 Problem Statement

Raw materials are often scarce and insufficient in developing countries (BFAP, 2022; Bjornlund et al., 2020; Krejci and Beamon, 2012; Trienekens, 2011). This makes it difficult to ensure that processors can operate sustainably, or above the breakeven utilisation threshold (BFAP, 2022; Bjornlund et al., 2020). The uncertainty of processors affects the entire value chain sustainability. This project's objective is to quantify the impact that different raw material (in this report also referred to as seed) availability levels and sourcing strategies of processors have on the value chain financial sustainability, by answering the following research question with three sub-questions:

- How can the impact of a change in available processor seed volumes on the entire value chain financial sustainability be evaluated?
    - How can the effect that different seed volume levels have on the entire value chain be illustrated?
    - How can the effect that different seed volume levels have on the entire value chain performance and financial sustainability be measured?
    - How to determine an ideal value chain with varying processor seed supply?

The project aims to understand the intricate nature of the Tanzanian sunflower value chain and create a representation of the system, to understand the effects of limited raw material of one node (in this project the processing node) on the entire value chain. The goal is to quantify the impact that an unreliable, or reliable, seed supply can have on the value chain's financial sustainability, as it affects the processor's profitability, which affects the seed market. This project's objective is to quantitatively illustrate these effects by using a system dynamic model, as further discussed in Section 1.3, as system dynamics can help to identify unexpected or unspecified outcomes of a decision or event (Khoshneshin and Bastan, 2014), and is very effective in testing different scenarios (Ahmadvand et al., 2013).

The research question includes an optimisation aspect to improve understanding of the value chain trade-offs by determining the ideal amount of seed to be processed to maximise the total value chain financial sustainability, given the current state of the value chain. More specifically, the optimisation aims to determine the volumes sourced locally versus imported to maximise profit, given the trade-off between the different sources' prices and cost reductions (efficiency gains due to continuous processing).

1.3 Research Design

System dynamics is based on system thinking, a way to describe and understand the causalities and interrelationships of variables in a system. System dynamics quantifies the impact of the interactions and develops a time-dependent view. It bases computer-aided simulation modelling on feedback system theory that complements the system thinking approach (System Dynamics Society, 2023). The approach has widely been used to analyse the behaviour of value chains under different uncertainties and aims to assist the decision-making of complex and dynamic systems (Angerhofer and Angelides, 2000).

The developed model represents the value chain as a system dynamic simulation model that illustrates the interconnectivity of the industry and the effects of different scenarios on the different parts of the value chain, as well as on the value chain as a whole. The model focuses on illustrating the change in volumes, prices and costs of each node (the producer, seed trader, processor, oil trader and cake trader nodes) in the value chain, to calculate the net income of each node and represent the value chain's financial sustainability as recommended by Aramyan et al. (2007); Bowers (1995); Crowder and Reganold (2015); Valenti et al. (2011); Zhen and Routray (2003). In this project, different raw material availability levels and sourcing strategies of the processing node are modelled to analyse the effect on the entire value chain's financial sustainability. The results aim to indicate if the change in seed supply or source has a positive or negative impact on the value chain's financial sustainability.

The scenarios were selected to illustrate the change in seed availability, as specified in the problem statement (Scenarios 1 and 2), while also taking different sources into account as possible solution options (Scenarios 3 and 4). The base model and the scenarios were modelled and run from 2022 to 2032, and analysed in the system dynamic model.

Base Model: The base model illustrates the current situation of the Tanzanian sunflower value chain and projects the possible future by running the model from 2022 onwards for ten years. The base model provides a benchmark or baseline to compare the scenarios to a current state and determine if the change imposed by the scenario has a positive or negative effect. It captures the prices, costs, volumes, gross margins and net income for each year and each node.

Scenario 1: The seed shortage scenario is important to understand the impact of different raw material shortage levels on the value chain's financial sustainability. It assists in understanding each node's performance and quantifies the impacts.

Scenario 2: The increasing seed supply scenario attempts to illustrate the potential value chain upliftment due to a more reliable seed supply for processors. The scenario tries to quantify the positive impact of having sufficient raw materials available on the entire value chain from seed producers to product traders.

Scenario 3: The source comparison scenario analyses the value chain without imports and with imports, to illustrate the impact that a structural change (like importing raw materials) can have on the value chain sustainability and highlights unintended consequences of the changes.

Scenario 4: The final value chain optimisation scenario analyses the value chain to find the ideal situation where the entire value chain operates at its best, as well as to find the ideal situation where the processor node operates at its best, given the current local and global dynamics and state. The model considers all dynamics of the system and ensures that no indirect influences are missed when trying to develop an ideal state for the value chain.

By finding the ideal amount of seed to be processed, the relationships and trade-offs between price, cost and volume can be studied to understand when an increase in seed volume is more beneficial, versus an increase or decrease in prices and costs. The optimisation scenario assists in understanding under what circumstances the value chain will perform at its best.

By knowing the ideal amount of seed to be processed, a better understanding can be developed of the required interventions to increase local processing to uplift the entire Tanzanian sunflower value chain. The optimisation scenario assists in understanding the objective of the processor node and how it relates to the entire value chain sustainability.

1.4 Research Methodology

According to Taylor (2005), multiple organisations have used value chain analysis to evaluate their sustainability and competitiveness . Value chain analysis provides a framework to unpack the dynamic flows of the value chain activities between the nodes in an analytical way (Kaplinsky et al., 2011). Value chain analysis has widely been applied to facilitate agricultural development interventions, however, the approach is predominantly static, and qualitative and struggles to measure the dynamic interactions of the performance of the whole value chain and its nodes (Higgins et al., 2010). Traditional analysis methods like operations research and analytical models often struggle to cope with the value chain network complexity (Dominguez and Cannella, 2020). To capture the complex nature of a food value chain, research suggests approaching the value chain as a complex adaptive system (Higgins et al., 2010). Simulation is often used for complex problems, as it can capture the complexities and examine causes and effects (Alony and Munoz, 2007), it has high flexibility for a huge variety of unforeseen problems and data variability to be analysed (Bruno et al., 2010). General simulation modelling objectives include understanding the supply chain and its key issues and processes; developing and validating scenarios of improvement; testing different alternatives; and quantifying the advantages of a scenario (Hirsch et al., 1998). These objectives are applicable to manage and analyse the risk of limited available raw material, as is the case in this project.

To analyse complex adaptive systems with simulation, multi-agent modelling, system dynamic models and network theory are suggested in a research study conducted by Higgins et al. (2010). While multi-agent modelling and network theory have also been widely applied, challenges remain around detail, data and structural value chain recommendations. On the other hand, system dynamics can understand and capture the entire value chain system, including the complexities and dynamics (Özbayrak et al., 2007; Rebs et al., 2019). The approach is crucial for problems with time-evolving variables since discrete event simulation cannot capture dynamic behaviour (Georgiadis et al., 2005). Furthermore, it can measure the performance of agricultural value chains in a qualitative way (Muflikh et al., 2021), with some system dynamic applications combining dynamic engineering representations with accounting models to economically optimise processes as illustrated by Ruth and Hannon (1997).

Systems dynamics is based on system thinking, which has been effectively applied to complex problems (Aronson, 1996). To analyse the complex adaptive Tanzanian sunflower value chain system, the system dynamics approach is used, which entails the steps illustrated in Figure 1.4 and discussed below. The steps are executed in an iterative approach, going back and forth between the steps until the model is validated and verified through testing.

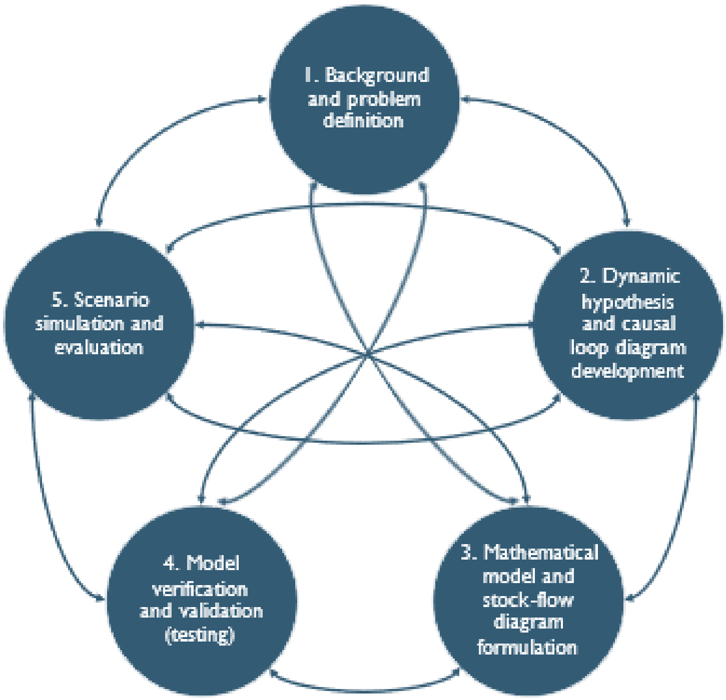

Figure 1.4: Iterative System Dynamics Approach

Source: (Sterman, 2000a)

1. **Background and problem definition** (Problem Environment, Problem Articulation and Objective, and System Dynamic Boundary Selection). The first step is to identify and truly understand the problem. A high-level analysis of the edible oil industry and the Tanzanian sunflower value chain is conducted in Section 3.1.1 to understand the environment in which the sunflower value chain operates, by looking at local production, consumption and trade volumes. The sunflower value chain is investigated by analysing the volume flow through the value chain nodes and the prices, costs and gross margins per node in the value chain, which were established from in-field research done by the BFAP (2022). This provides more detail and understanding of the effects of a change in seed volumes on producers, processors, traders and the value chain.

   A preliminary analysis of the impact of limited seed in the value chain is done to illustrate the importance and objective of the study and system dynamic model (Figure 3.5). The background and problem definition step is crucial to ensure that the modeller understands and represents the current situation and scenarios realistically and accurately. With the information from the problem environment, articulation and objective, the system dynamic boundary is defined to set specifications for the model developed in Section 3.1.3.

2. **Dynamic hypothesis and causal loop diagram development** is executed once a good understanding of the value chain has been established. The problem and dynamic theory are summarised in the dynamic hypothesis, which is a summary of the most important leverage points and their impact on the system (Sterman, 2000a).

   A deeper understanding is generated by developing the causal loop diagram of the Tanzanian sunflower industry. The causal loop diagram is developed from a typical agricultural value chain structure as seen in Figure 1.1; the Tanzanian sunflower value chain structure developed in the previous step and represented in Figure 3.3; a typical partial equilibrium model structure (Simchi-Levi et al., 2014); the supply and demand principles of volume and price (Smith, 2010); as well as the International Model for Policy Analysis of Agricultural Commodities and Trade Model developed by Rosegrant et al. (2008), and referring to the Tanzanian sunflower partial equilibrium model developed by BFAP (2022). The loops are further validated with a statistical analysis that determines the correlation between the identified variables in the causal loop diagram, discussed in Section 3.2.2.

3. **Mathematical model and stock-flow diagram formulation** is done from the causal loop diagram and statistical analysis of historic input data of prices and volumes gathered by in-field research done by the BFAP (2022). The mathematical formulation consists of multiple formulas representing the flow of raw material, stocks, information feedback, and changes in prices, area and yield. The mathematical formulation is modelled as a simulation model representing the stock-flow diagram that includes dynamic variables calculating the net income for each node in the value chain for the value chain financial sustainability indicator.

   The simulation model is generated in AnyLogic, where multiple scenarios can easily be run. The data feeding into the model is validated and summarised for the validation of the model as well as the base model and scenarios. The final simulation model is developed with an iterative approach that included the dynamic hypothesis, causal loop diagram, model formulation and validation and verification. The process is re-iterated until model validation and verification are achieved. If the validation and verification are unsuccessful, changes are implemented on the dynamic hypothesis and applied throughout the process (causal loop diagram, model formulation) up to model validation and verification to determine if the model is representative of the actual system.

4. **Model verification and validation (testing)** occurs by comparing the results to historic data (2012 to 2022), also known as the behaviour reproductivity test (Bala et al., 2017; Sterman, 1992). Furthermore, the model is tested with the boundary adequacy test, which ensures that all key elements are included in the model (Bala et al., 2017); the logical behaviour test, which tests that the results generated by the model are logically feasible (Sterman, 2000b); the structural assessment test, that aligns the model structure with the real-life system (Bala et al., 2017; Qudrat-Ullah, 2005); the dimensional accuracy test to ensure that the dimensions in each stock, flow or dynamic variable are correct given their formula (Bala et al., 2017; Pejić-Bach and Čerić, 2007); the extreme condition test which evaluates that the results generated by the model in extreme conditions are correct (Sterman, 2000b); and the parameter validation to ensure that the data entered into the model is accurate (Bala et al., 2017; Qudrat-Ullah, 2005).

5. **Scenario simulation and evaluation** occurs once confidence in the model has been established. The model is set to the year 2022 to project the expected behaviour for ten years, given the input data for the expected sunflower yield, world seed, oil and cake prices, population and inflation. The results of the base model are captured as a baseline for scenario comparison.

   Finally, the scenario changes are developed and imposed on the model to analyse the results of the value chain's performance and financial sustainability under different conditions by looking at the profitability or net income of each node, as well as the total value chain. For the first scenario, the available seed for processors is changed by decreasing the yield in increments of 10% until half of the expected seed is available while assuming that imported seed is too expensive and ensuring that raw material levels are truly limited. The impact of an increase in seed supply at processors is also modelled to see the extent of the positive impact. Different sourcing strategies are analysed by decreasing the available seed at processors and allowing seed imports versus previously not importing seed. From the scenarios, the results are analysed and discussed to paint a complete picture of the effect that different available seed volume levels and alternative sourcing strategies have on the Tanzanian sunflower value chain's financial sustainability and its nodes.

   Finding the best possible value chain performance may be beneficial to provide insight to value chain stakeholders and policymakers. Thus, the model is further developed into an optimisation model that varies the volume of seed processed at the processing node to find the maximum total value chain and processor net income. The net income of the solutions of the optimisation scenarios is calculated and compared to the base model, as well as extreme (maximum and minimum) processing volumes to ensure that the solution of the optimisation model is indeed the ideal solution. This model extension is used to understand the value chain nodes better and may provide valuable insight for intervention identification to uplift the value chain to an improved state, as it considers the trade-off between volume and price while maximising profit.

1.5 Expected Contribution

The key contribution of the model is to incorporate the impact of processor profitability, due to a change in raw material availability, on the entire value chain. Thus, to quantify the impact that a change in processor profitability has on the value chain financial sustainability through indirect feedback in the system dynamic model.

Some crop price and production system dynamic models have been developed, but as far as the author of this report is aware, no system dynamic models have been developed for the Tanzanian sunflower value chain.

Furthermore, the model can optimise the value chain by determining the ideal seed purchases of processors to maximise the value chain's financial sustainability. According to the author and the conducted literature review, optimising the total value chain system dynamic model has not been done before. The optimisation scenario assists in determining what is the best possible amount of seed to be purchased by processors to maximise value chain net income. This assists in understanding how much local seed production is required to make processors and the value chain as profitable as possible, and thus uplifting the value chain. The value chain optimisation helps to understand what is required to achieve an upgraded state of the industry. Often interventions promote volume increases, while further interventions are required to support the volume increase to be handled downstream of the value chain. Running the optimisation model and the basic system dynamic model together can assist in identifying the ideal state, interventions to achieve the ideal state, and bottlenecks that prevent the ideal state from realising.

The model is tailored for analysing the financial sustainability of an agricultural value chain under different processor raw material volume scenarios. The model helps to answer the questions regarding the investment decision of the private sector by looking at the financial situation of the value chain. Determining the current financial state of the sunflower value chain in Tanzania, and the potential future financial state (under different scenarios) can be helpful for policymakers to uplift the value chain. It can inform decision-making to increase the sustainability of the entire Tanzanian sunflower value chain, and the financial health of all stakeholders. It can further assist in dealing with black swan events that have a high impact but low probability and are difficult to predict, but where the impacts or consequences can be analysed from a model, by running different extreme scenarios.

1.6 Document Structure

The following chapter (Chapter 2) discusses important literature regarding the problem environment and previous research on the topic. The section starts to discuss different approaches for analysing agricultural value chains, before going into more detail about the systems approach of value chain analysis (Section 2.2) and performance indicators for scenario evaluation (Section 2.3.1).

Chapter 3 executes the project as discussed in Section 1.4 by articulating the problem and developing a system dynamic model through the dynamic hypothesis, causal loop diagram, mathematical formulation and validation and verification (representing 2012 to 2022).

Afterwards, Chapter 4 develops the projected future base model (representing 2022 to 2032) and runs the different scenarios and analyses the solution. Finally, Chapter 5 concludes the report and makes suggestions and improvements for further research on this topic.

Literature Review

The literature review was structured according to the sub-questions of the problem statement (Section 1.2) on how to illustrate and measure the impact of a change in available processor seed volumes on an entire value chain, and how to optimise the value chain. The first part of the review looked at methodologies to analyse and uplift agricultural value chains to quantify the current state of the value chain and improve sustainability (the first part of the research question). The section delved deeper into the concept of seeing a value chain as a complex adaptive system and appropriate analysis methods. The system dynamic approach was unpacked and discussed with examples where system dynamics has been applied in the agriculture and value chain sectors (Section 2.2), and Section 2.2.3 looks at where system dynamics has been used and applied in combination with optimisation models (the third part of the research question).

The final section (Section 2.3) of the literature review investigated indicators to determine the performance measures and financial sustainability of the value chain and its nodes (the second part of the research question).

2.1 Supply and Value Chain Analysis

Supply chain management is defined by the Supply Chain Council (2012) as the planning and management of activities that are involved in sourcing, procuring, and converting raw materials into products. Furthermore, all logistics management activities coordinate and collaborate with suppliers, intermediaries, third-party service providers, and customers (Croom et al., 2000). Supply chain management balances supply and demand and integrates business planning. It can be extended to value chain management, which includes the value-adding characteristic of a business process (Porter and Kramer, 1985). A value chain is a set of interrelated activities that companies use to develop a competitive advantage (linked to value chain sustainability), while a supply chain is the interrelated activities to deliver a product or service to the customer (Taylor, 2005).

Value chain analysis is a tool to do a multi-dimensional performance assessment of the supply chain used by organisations and industries to assess their competitiveness and sustainability (Taylor, 2005). The goals of value chain analysis include identifying change agents for technical and policy interventions; assisting to understand overall trends of industrial reorganisation; and increasing customer satisfaction (AFAAS, 2014). When analysing the effect of limited raw material on the Tanzanian sunflower value chain, the learnings would ideally be used to inform technical and policy interventions to improve the value chain sustainability. Furthermore, understanding the trends of the current sunflower industry and potential trends under different scenarios is the aim of this study, and increasing customer satisfaction can also relate to increasing sustainability as both are improvement indicators. Hence, the goals of value chain analysis can be directly related to the goal of this project.

Instead of different products or companies competing, it is more common for entire supply chains to compete against each other. For this reason, companies do not drive cost decreases if it negatively influences the supply chain partners. Instead, the goal is to make the entire supply chain more competitive. This shift can be attributed to the required rapid responses to meet customer preferences. Thus, supply chain management is becoming more important for business competitiveness as it captures intra- and intercompany integration and management (Croom et al., 2000). This is also true for value chains, where strong value chain collaboration is required to grow the development of increasingly complex agro-food value chains (Humphrey and Memedovic, 2006), supporting the reason for analysing the entire value chain, as opposed to only the processing node directly affected by limited raw material.

2.1.1 Agricultural Value Chain Analysis

Agricultural value chains are characterised by low-value end products, declining gross margins, very large participants network across countries (as opposed to linearly integrated businesses with limited suppliers, producers, and processors), strong social drivers and large environmental and climatic variability (Higgins et al., 2010). Further characteristics include product disassembly (where the product starts as a whole unit and is then split into a variety of finished products with independent demand), long lead time and a cultural environment affecting the price and perception of the product (Taylor, 2005). These characteristics make agricultural value chains complex.

There have been multiple different studies conducted to analyse agricultural value chains. Porter and Kramer (1985) developed a value chain tool, with five steps. Firstly, the primary and supporting activities need to be identified by mapping the value chain, then the importance of each activity must be identified and established, thirdly identify cost drivers for each value chain activity, fourthly identify the links between activities and finally identify opportunities to reduce costs (Porter and Kramer, 1985). In an article published in the popular research journal of the International Food and Agribusiness Management, a framework analysis of the agricultural value chain in developing countries used Porter's five forces and focused on analysing infrastructure, resources, geographic position, technology, educated labour, distribution and communication (Trienekens, 2011). Porter's five forces approach is very basic but comprehensive and can give a good summary of the current state of the value chain that needs to be analysed and modelled. However, it does not allow for multiple scenario development and analysis, as required for the problem under investigation, to capture the effect of changing raw material availability levels.

Another common analysis is the "best value supply chain", where the goal is to balance supply chain information, maintenance and cost. The best value supply chain aims to provide customers with superior value regarding quality, speed, flexibility and cost. The best value supply chain differs from a normal supply chain in terms of strategic sourcing, supply chain information systems, logistic management, and relationship management (Ketchen et al., 2008). The approach is more applicable for operational supply chain management, focusing more on quality, speed and flexibility, where the problem at hand requires more strategic high-level analysis.

A research article by Hines et al. (1998) developed the value stream management approach, an approach for supply chain improvement in agricultural food chains. The practical tools of the value stream management approach were utilised in combination with a case study approach (basing findings on the specific group) and action research (which requires the researcher to be involved in the improvement process). Value stream management is an operational and strategic approach for an effective change of cross-company or cross-functional processes needed for a lean enterprise. It includes data gathering, analysis, planning and implementation (Hines et al., 1998). The value stream management approach is appropriate for the analysed value chain, however, a weakness of the approach is that the current or future state of mapping techniques do not include financial measurements of current operational costs and the potential benefit of lean improvements. These aspects are all critical requirements for the problem statement of this project. Another problem identified was the fact that the approach required significant resources and time (Taylor, 2005). Furthermore, the approach required the researcher to be involved in the improvement process, which is impossible for this project as the improvement needs to be done by the Tanzanian government and sunflower stakeholders which requires significant stakeholder engagement and buy-in, which is excluded from this study.

All the approaches above are very good in analysing the situation of the value chains, however, they are more focused on the current value chain performance and do not provide scenario analysis. More specifically, do not analyse the impact of a change in raw material availability on the value chain's financial sustainability.

Metaheuristics aims to develop high-level strategies for solutions that are effective and optimised (Dutta and Mahanand, 2022). It is a general problem-solving technique, that aims at finding a sufficient solution applicable to a wide variety of difficult optimisation problems, at a reasonable computation time where other techniques have been unsuccessful (Salcedo-Sanz, 2016). Metaheuristics have been used to represent agriculture value chains, like designing a closed-loop supply chain for the coconut industry (Gholian-Jouybari et al., 2023), the sugar cane industry (Chouhan et al., 2021) and the citrus industry (Roghanian and Cheraghalipour, 2019).

The approach has yielded a lot of success due to its flexibility, given the ability to adapt to the required problem in terms of solution quality and computation time, and by keeping the formulation unspecified (not requiring the formulation to meet any specific demands). However, this makes it difficult to get good performance from the models and makes it difficult to use the approach, as no universal methodology is provided. Furthermore, the approach has been criticised due to its lack of scientific rigour in testing and comparing different implementations (Sörensen and Glover, 2013)

Operations research has also been used to model agricultural value chain opportunities given that the activities are isolated (focusing on one specific aspect and not on the value chain interrelations and knock-on effects). Examples of operations research in the agricultural industry include the optimal location of facilities (Lucas and Chhajed, 2004), optimal selection of various crops over multiple years to maximise farmer profitability, machine selection and labour activity trade-off (Recio et al., 2003), crop planning under different environmental conditions (Janová, 2012; Rădulescu et al., 2014), optimum storage capacity to manage post-harvest losses by minimising establishment cost, food grain loss, transport cost, inventory holding cost, carbon emissions, and risk penalty costs (Mogale et al., 2020), water management, land use and environmental protection (Bournaris et al., 2015). However, operations research uptake in agriculture remains limited due to the complexity of the value chain interactions; mathematical representations being inconsistent; difficulty to quantify factors; huge data requirements; and decision-makers being influenced by social situations (Beynon et al., 2002). Agricultural value chains are not isolated and have high interconnectivity. Because a whole view and understanding of the agricultural value chain is often lacking by the modeller, the application of operations research has been limited. To incorporate the larger overall value chain view, research indicates a great success in integrating operations research with simulation modelling (Oliveira et al., 2016), specifically system dynamics (Größler et al., 2008).

Lembito et al. (2012) researched how to achieve competitive advantages for agribusinesses and recommended utilising system dynamic simulation modelling and the Supply Chain Operations Reference model (SCOR model from the Supply Chain Council (2008)). The research assisted agribusinesses in critically examining issues and strategies to deliver value to consumers while remaining globally competitive and ensuring a competitive advantage. The methodology used the SCOR model to measure and collaborate with value chain partners for mutual performance benefits, while system dynamics considered the causal relationships between variables and analysed the operational performance impact on the supply chain with simulation modelling (Lembito et al., 2012). The study illustrated the advantage of using system dynamic modelling to increase the competitiveness of agribusinesses in an uncertain market and turbulent economic conditions, as is the case for the Tanzanian sunflower industry. The SCOR model was deemed effective at quantifying the reliability, responsiveness, flexibility, cost and asset management of the supply chain (Lembito et al., 2012). However, the SCOR model is very extensive, considering a vast amount of indicators that go beyond the scope of the current study to measure the financial sustainability of the value chain.

2.1.2 Value Chain as a Complex Adaptive System

While Rebs et al. (2019) believes that analytical models, mathematical programming and simulation methods are suitable quantitative modelling approaches, research by Dominguez and Cannella (2020) suggests that traditional methods like operations research, analytical models, and continuous and discrete time differential equations, often struggle to cope with the value chain network complexity. Value chains are complex and dynamic systems with delays, nonlinearities and network feedback loops (Lembito et al., 2012). Value chain entities are highly interdependent, as a decision made by an entity affects the rest of the entities in the value chain. Consequently, the collaboration willingness of the value chain entities and their coordination abilities highly affect the value chain performance. According to Wen et al. (2012), a lot of research has been conducted to develop predictive value chain network models for performance improvement, but most research focuses on the microscopic view and does not consider the entire value chain performance. Value chains have become increasingly complex due to wider product variety, smaller production lot sizes, globalisation, more customer-tailored products, and an increase in outsourcing (Perona and Miragliotta, 2004).

To capture the complicated and intricate nature of a food supply chain, like the Tanzanian sunflower value chain, research suggests approaching the value chain as a complex adaptive system (Higgins et al., 2010). A complex adaptive system is an interconnected system with entities that make their own decisions and evolve to self-organise over time (Pathak et al., 2007). A complex adaptive system can change according to feedback or memory, making it resilient. Furthermore, complex adaptive systems are usually open systems, that interact with the environment, creating feedback. Most importantly, complex adaptive systems show emergence, as the whole is more than the sum of the components, and the connectivity creates a new property (Evans and Turner, 2017). These characteristics apply to the Tanzanian sunflower value chain, as the value chain nodes are highly connected; the system changes according to feedback from one node or variable to another in the system; the system interacts with the political environment as well as other factors outside of the system like weather; and the entire sunflower value chain comprises of multiple nodes that create a new value chain property together, illustrating the emergence of the system.

Simulation is often used for complex problems, as it can capture the complexities and examine causes and effects (Alony and Munoz, 2007). A simulation model is a unique modelling tool that uses existing data and knowledge to examine the impact of different scenarios in a low-risk and low-cost environment and provides a dynamic environment for modelling (Freebairn et al., 2016). Simulation modelling has high flexibility for a huge variety of unforeseen problems and data variability to be analysed (Bruno et al., 2010). The ability to capture and analyse large flexibility and wide variety is very important in the agricultural sector, as it is subject to many uncontrollable factors (Krejci and Beamon, 2012). According to an extensive literature review conducted by Hosseini et al. (2019), simulation modelling is crucial for complex problems that have behavioural changes in the system over time, like the problem under investigation. General simulation modelling objectives include understanding the supply chain and its key issues and processes; developing and validating scenarios of improvement; testing different alternatives; and quantifying the advantages of a scenario (Hirsch et al., 1998; Oliveira et al., 2016). The goals relate directly to the project objective of illustrating and measuring the change in value chain financial sustainability by modelling and analysing different scenarios before imposing any changes on the actual value chain.

Simulation Modelling Methods of Complex Adaptive Systems

To analyse complex adaptive systems with simulation, as found in agriculture, multi-agent modelling, system dynamic models and network theory are suggested by Higgins et al. (2010). The three methods are useful to represent agricultural value chains, and their components and behaviours, and to observe patterns and interactions.

The first method is multi-agent modelling, which uses behavioural rules of autonomous entities and interaction rules to simulate consequences across the network of entities (Higgins et al., 2010). According to Dominguez and Cannella (2020) multi-agent simulations are suitable for decentralised supply chain networks that are complex due to the many elements and processes between the elements. Multi-agent systems are capable of representing many heterogeneous agents that act independently (Bandinelli et al., 2006). Even though multi-agent modelling has many advantages, it is still quite uncommon in food supply chains. Challenges include overwhelming the model details such that the research question is lost, as well as gathering sufficient reliable data to build a representative model (Krejci and Beamon, 2012). Gathering data is generally a struggle in Africa, adding to the reliable data gathering challenge (BFAP, 2022).

Network theory focuses on the structure of interactions between value chain components, and how the network structure affects the performance of the system (Bodin et al., 2006; Janssen et al., 2006; Newman and Dale, 2005). Network theory can be more objective than operations research models because it combines network structure with calculations of operations research. However, network theory in its pure form does not make any structural value chain recommendations.

System dynamics aid in understanding the causes of behavioural change, especially the non-linear characteristics (Sterman, 2000b). Systems dynamics is based on system thinking, which has been effectively applied to complex problems and to improve the performance of complex projects (Aronson, 1996). System dynamics has widely been used to analyse the behaviour of supply chains under different uncertainties. It aims to assist the decision-making of complex and dynamic systems, by assisting in strategy and policy design and analysing different disruptions and risks (Angerhofer and Angelides, 2000). System dynamics can aid in understanding the entire supply chain system, as well as analysing the interactions between different components (Özbayrak et al., 2007).

Agricultural industries, like the Tanzanian sunflower industry, are biological systems which have delays and cyclic behaviour. System dynamics illustrate feedback between biological phenomena with market behaviour, as well as the impact that exogenous shocks (like a drought) have on a system. This assists in empirically evaluating the impact of different policies and prioritising investments (Rich et al., 2011). To identify the required policy or investment in the Tanzanian sunflower value chain for sustainability improvement, analyses need to be conducted and scenarios need to be run to identify the required change, and the effect of the change needs to be quantified. This can be done with a system dynamic simulation model.

The characteristics of system dynamics can be related to the required factors for analysing an agricultural value chain. In a framework to analyse agricultural value chains in developing countries, three important factors were identified, namely to identify critical components that prevent a value chain upgrade; to analyse the value chain in terms of network structure, value-added and governance mechanisms; and defining the upgrading options concerning the analysis (Trienekens, 2011). Developing a system dynamic model of a value chain creates the network structure of the value chain, which can be analysed by running different scenarios which assist in understanding the value chain and in identifying the critical components that prevent a value chain upgrade. Thus, systems dynamics was selected as the appropriate approach due to its suitability to the problem, further discussed in Section 2.2.

2.2 System Dynamics

System dynamics has many advantages and opportunities. It can illustrate different parts and perceptions of a problem and is very effective in analysing a system (Ahmadvand et al., 2014). It can help to identify unexpected or unspecified outcomes of a decision (Khoshneshin and Bastan, 2014) and is very effective in testing different scenarios (Ahmadvand et al., 2013), and determining the long-term effects of implementing a decision (Bastan et al., 2013). In short, it increases the understanding of change. System dynamics assists in structuring ambiguous characteristics in operations management like feedback loops, accumulations and delays (Größler et al., 2008). System dynamic models are more descriptive, as they aim to investigate a system rather than derive an analytical model (Akkermans, 1993). It is very helpful for incorporating qualitative information into a quantitative model and analysis (Moosivand et al., 2019). However, the model still requires the creativity of a human mind to specify the variables and feedback iterations (Salmasnia et al., 2012). Furthermore, lack of information can be a huge limiting factor, yet approximations may help to understand the structural behaviours of a system (Bastan et al., 2016).

The system dynamic approach is crucial for problems with time-evolving variables since discrete event simulation cannot capture dynamic behaviour (Georgiadis et al., 2005). System dynamics modelling is suitable to simulate and analyse complex and dynamic systems, utilised for strategic long-term decision-making (Rebs et al., 2019). According to a study by Dizyee et al. (2016), there are limited quantitative approaches to analyse the dynamics of value chains, their key role-players, interventions and effects. Furthermore, system dynamic models capture market interactions and the behaviour of value chain actors, whereas partial equilibrium models only look at the sector level (Dizyee et al., 2017). System dynamics also illustrate the impacts of technical and institutional responses due to policies, and dynamic structures that partial equilibrium models often miss (Rich et al., 2011).

Größler et al. (2008) investigated the impact of system dynamics in operations management as a structural theory and concluded that system dynamics is well utilised in supply chains, specifically to analyse the bullwhip effect of inventory, and material flow between companies in a supply chain. Furthermore, system dynamic models offer theories about supply chain issues and a structural lens to perceive and manage supply chains (Größler et al., 2008). System dynamics was applied to model the production, distribution and consumption of a supply chain, specifically to quantify the impact of inventory levels. The study simulated the initial current system, as well as the improved system, and analysed the system behaviour as well as inventory cost and impact on the system (Ayomoh et al., 2004).

System dynamics originated from industrial dynamics and has been applied across numerous differentiating problem types, including value chains (Angerhofer and Angelides, 2000). A comprehensive literature review executed by Muflikh et al. (2021), investigated literature regarding the application of system dynamics in value chain analysis. Three main objectives to apply system dynamics in agricultural value chain analysis were identified. Namely to investigate or model the dynamic behaviour of the agricultural value chain system; to assist in understanding the underlying problems and their impacts; and to simulate different scenarios or interventions to improve a value chain (Muflikh et al., 2021). All of these objectives apply to the current problem of analysing the behaviour of the Tanzanian sunflower value chain to assist in understanding the value chain problems and behaviour and to simulate the impact of different seed availability volume level scenarios.

2.2.1 System Dynamics Implementation in Agriculture

System dynamics has been utilised in the agricultural sector as discussed in this section. In an article published by Lembito et al. (2012) which applied the system dynamics approach to the Indonesian crude palm oil value chain, it was concluded that the approach is very useful in assisting agribusinesses to improve competitiveness under uncertain demand and unstable economic conditions (similar to Tanzania's sunflower industry). The approach executed by Lembito et al. (2012) consisted of broad industry analysis, generating the simulation model, running the scenarios and analysing them with performance indicators from the SCOR reference model.

System dynamics was used by Bastan et al. (2016) to holistically analyse and develop sustainable development principles for Iran's farming industry, specifically to understand the complex system of agricultural land loss. The sustainability goal aligns with the current study's sustainability goal, providing a good base for the study's approach. Bastan et al. (2016) analysed the dynamics of farming and land-use change, specifically looking at the change in farming level due to construction, water availability and economy. First, the problem was researched and the different relationships were explained. From this, the dynamic hypotheses were constructed. Then a holistic view of the system was developed, from which the cause-and-effect diagram, and then the stock and flow diagram was developed. The next step was to validate the model. The extreme condition test, boundary adequacy for structure test, structural behaviour test, model equation logic test, and dimension consistency test were used as validation. After validation, the leverage points of the system were identified to develop scenarios. In the case of agricultural land loss, the profit gained from farming, and the water required for farming were identified as leverage points. These informed the three scenarios, namely to increase profit gained, utilise modern irrigation techniques, and block unauthorised wells. When running the scenarios, the analysis always looked at areas under farmland production use over ten years, and water level over time. The research by Bastan et al. (2016) stated that limited economic information restricted the analysis conclusion, but did still help to understand the structural behaviour of the system.

A system dynamic model of a potato value chain was developed by Rich and Dizyee (2016) representing the value chain from production to storage and finally to market. The production depended on the available area (which was fixed), planting month and yield (modelled as a double log function of expected potato price and yield elasticity). After harvest, the potatoes were either sold as fresh produce or stored. The potatoes were modelled to be sold fresh if the potato price was higher than the fresh potato price plus storage cost. The selling price of potatoes was modelled as a function of inventory, if inventory was below the desired level, more potatoes were stored, which increased the price. In return, the price change affected the demand that was modelled as a double-log function of income and price.

All data was obtained from open-data sources or literature studies, and the model was developed in IThink software and ran monthly for 60 years and measured the impact on price. The model was run for different climatic conditions that impacted yield, a subsidised storage cost policy intervention scenario, and a reduction in the postharvest loss policy scenario. Further scenarios included intra-state trade due to improved infrastructure and a reduction in transactional costs. For each scenario, the price coefficient of variance, cumulative farm revenue (as an indication of farmer welfare) and consumer surplus (as an indication of consumer welfare) were calculated (Rich and Dizyee, 2016).

A clear advantage of a system dynamic model could be seen in the results that illustrated that an expansion in cold storage would be beneficial for the potato value chain as it provided potato producers with an alternative market and reduced price variability (Rich and Dizyee, 2016). This impact would have been very difficult to identify without a system dynamic simulation model. The model structure represented the entire value chain from producer to consumer nodes, which is also relevant to the current Tanzanian sunflower value chain. Furthermore, the methodology of modelling price as a flow, as applied by Rich and Dizyee (2016), is applicable to the current project, as limited raw material volumes affect prices. The type of scenarios that were run is insightful for scenario development of the Tanzanian sunflower project, as well as the decision-making of the model. Finally, it is important to note that the study by Rich and Dizyee (2016) supports the use of open-data sources, as data availability is often a problem in developing countries like Tanzania.

The strategy to expand a vertically integrated aquaculture company was modelled and analysed by Oleghe (2020) through system dynamics by modelling the financial impact of expanding the company with its own money versus getting a bank loan. The base model was constructed with information from literature as well as expert interviews and questionnaires. The model consisted of a system dynamic that included fish volumes (from supplies to production to fish shops) and cash flows, as well as a discrete event sub-model that represented the building of new fish shops. The model was verified according to dimensional consistency and logicality, and the model was tested by checking that it ran normally when removing elements that affected the base model. The model included a chain of "if statements" specifying the time to build a shop given different available cash levels. The fish sales per day and cash levels were tracked over time. The approach considered the interactions of important variables, time-dependent events and uncertainty (Oleghe, 2020). This study clearly illustrated system dynamics' successful application in investment decision analysis, which could be used to analyse the investment in further sunflower seed processing capacity in Tanzania. The integration of a system dynamic model with a discrete event model is also very enlightening and may be used for potential further analyses and questions.

Olivares-Aguila and ElMaraghy (2021) used system dynamics to develop a framework that reflects supply chain behaviour when faced with disruption. The model allowed full and partial disruption scenario analysis and illustrated the effects on the service level, costs, profits and inventory levels. The model results illustrated the importance of analysing the entire value chain as one system. The research highlighted the importance of making the correct assumptions when building the model, and the importance of examining other system configurations (Olivares-Aguila and ElMaraghy, 2021). This study supports the use of system dynamics modelling for this project, as limited seed availability in the Tanzanian sunflower industry can be seen as a disruption, for which the effects on the entire value chain need to be illustrated and analysed as done by Olivares-Aguila and ElMaraghy (2021).

Many more examples of system dynamic implementation in the agricultural sector exist. System dynamics was used to analyse the Indian sugar industry as an effective management tool that solved complex dynamic issues (Javalagi and Bhushi, 2007). Food supply chain system dynamic models include the chicken supply chain under a bird flu crisis (Le Hoa Vo and Thiel, 2011), a non-perishable supply chain in a monopolist environment (Kumar and Nigmatullin, 2011), a grain supply chain for policy advice regarding cost reduction (Sachan et al., 2005), strategic issues of a food supply chain, specifically the problem of long-term capacity planning (Georgiadis et al., 2005). Further examples are given in the system dynamic book by Bala et al. (2017), and include "Modelling of Boom and Bust of Cocoa Production Systems in Malaysia" which modelled the high and low production levels of cocoa, "Modelling of Hilsa Fish Population in Bangladesh" represented the population dynamics of fish, "Modelling of Food Security in Malaysia" illustrating Malaysia's rice production and self-sufficiency in relation to population growth and "Modelling of Supply Chain of Rice Milling Systems in Bangladesh" with its milling system to represent inventory and price levels to create the bullwhip effect. All examples follow the approach discussed in Section 2.2.2.

2.2.2 System Dynamic Approach

System dynamics has been characterised as the required tool for system analysis, and for perceiving problems and developing solutions. System dynamics is based on system thinking, a way to describe and understand the causalities and interrelationships of variables in a system. System dynamics then quantifies the impact of the interactions and develops a time-dependent view. It bases computer-aided simulation modelling on feedback system theory that complements the system thinking approach. The system dynamics approach was first developed by Forrester at the Massachusetts Institute of Technology in 1950. The approach consists of five steps, which are illustrated in Figure 2.1 and discussed as an iterative approach with multiple feedback loops (Sterman, 2000a).

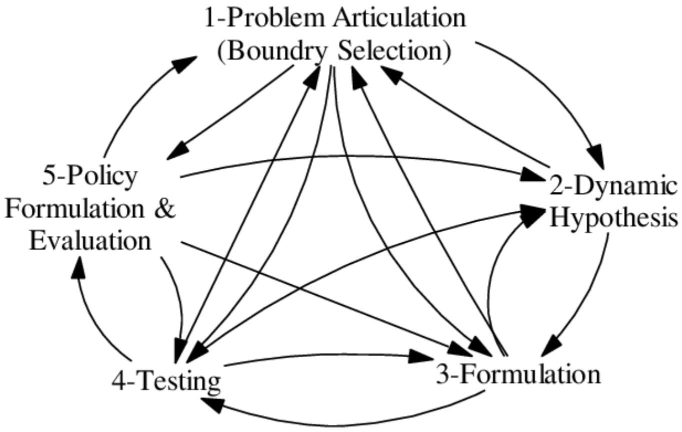

Figure 2.1: Iterative System Dynamics Approach

Source: (Bastan et al., 2016)

1.Problem Articulation: The first iterative step includes understanding the problem environment, defining the boundary and specifying the objectives. To understand the problem and identify the problem's causes, the scope of the study should be clearly stated, and the problem statement should be created from historical and statistical data, studies and reports (Bala et al., 2017). The system boundary refers to the limited causalities included that explain the observed problematic behaviour. Furthermore, the system boundary should ensure that all endogenous variables and views are included, as well as specify the time horizon and time units (Martinez-Moyano and Richardson, 2013). This step should provide insight into the Tanzanian sunflower industry to ensure that the problem and its environment are correctly captured by identifying all endogenous variables that affect the industry as well as the industry boundary and scope, to satisfy the objective of representing the industry accurately.

2.Dynamic Hypothesis: The second step is to develop a hypothesis around the dynamics of the system by conceptualising the system. The dynamic hypothesis aims to identify and define important feedback loops that drive the model's system behaviour. The acquisition, storage and input conversion of a supply chain creates important feedback loops between partners. System dynamics aims to capture these influences (Sterman, 2000a). The second step should capture these dynamics of the Tanzanian sunflower value chain.

The four main approaches to developing a system dynamic model are to model according to the causal loop diagram (Coyle, 1997), model based on resource identification and their state (Wolstenholme, 1990), model using generic structures of a specific field (Wolstenholme, 2004), and formulating the model according to component strategy (Forrester, 1968). The most common approach to explain the model structure is the model based on a causal loop diagram, while the generic structure approach is very handy as a generic structure (like a value chain) can be applied to a specific problem (Pejić-Bach and Čerić, 2007). However, the generic structure approach needs to be used with caution to ensure that an incorrect structure is not forced onto a problem without realising that the generic structure does not fit the system, as not every system that produces a specific growth trend can be modelled with any given structure that produces the same growth trend (Forrester by Lucia Breierova, 1996).

Both of these approaches are very useful for the current project that requires a good representation of the unique value chain structure that is specific to the current Tanzanian sunflower value chain being modelled. The project can utilise generic structures, like the supply and demand principle that applies to all free-market products (Smith, 2010), or a typical agricultural value chain (Van der Vorst et al., 2007). Hence the system dynamic model can be developed by starting with a generic value chain structure (as depicted in Figure 1.1), a generic supply and demand structure, and a generic crop partial equilibrium model, and then be tailored to represent the true Tanzanian sunflower value chain reality with the causal loop diagram. The causal loop diagram illustrates the feedback structures between variables while serving as a causal hypothesis during model development (Bala et al., 2017).

3. **Formulation:** The stock-flow diagram is constructed in the third step and represents the flow of information and material, and adds mathematical equations that represent the relationships of the dynamic hypothesis. In the stock-flow diagram, the interrelationships between stock (state) and flow (rate) variables are modelled. Production and sales can be examples of input flows, while stocks and work-in-progress are output flows. System dynamics assumes that changing the input flows will change the output flows. In the stock-flow diagram, a negative feedback loop is goal-seeking, where the system seeks to return to its equilibrium after a disturbance, while in a positive feedback loop, a disturbance results in further change along the supply chain (Sterman, 2000a). During formulation, the model is mathematically mapped with a system of differential equations, which is numerically solved with simulation software like iThink, Stella, Vensim, or Powersim (Georgiadis et al., 2005).

   There are many different system dynamic simulation modelling softwares. The most commonly used packages include Dynamo, iThink, Stella, Powersim Studio and Vensim. Further software packages include AnyLogic, Dynaplan, GoldSim, Barkley Madonna, Powersim Studio, Simile, Simgua, TRUE, Ventity and Simcision (System Dynamic Society, 2023). AnyLogic has high-level flexibility and user functionality. It provides multi-method simulation to support agent-based modelling, discrete event modelling and system dynamics in multiple industries (Biolyse, 2018). Combining different modelling techniques can be very beneficial to model a true representation of reality and expand the range of possibilities within modelling. Due to AnyLogic's multi-method simulation, specifically, its ability to combine system dynamic modelling with optimisation, and the project executor's experience in AnyLogic and the accessibility to it, this project's system dynamic model was executed in AnyLogic.

4. **Testing:** It is important to test a model for validation and verification. Verification is the process of ensuring that the model is transformed correctly, ensuring that the correct outcomes are generated based on the provided income. While validation ensures that the model behaves accurately and consistently with the objective of the project (Balci, 1998). Model validation is gradually achieved as the model progresses through the iterative approach, as well as the model structure and behavioural tests. Confidence in a model can be achieved by a wide variety of tests, focusing on model structure, model behaviour and the model's policy implications. According to Forrester and Senge (1979), not all tests are required for model validation, but structure and behaviour tests are crucial.

   The model structure tests can be classified into structure verification, parameter verification, extreme condition, boundary adequacy and dimensional consistency tests. The structure verification test compares the model equations with the relationships in the real system by ensuring that the model structure aligns with the descriptions of the system (Bala et al., 2017). This can be achieved by comparing the modelled structure to other studies with similar model concepts (Qudrat-Ullah, 2005). The parameter verification test evaluates the parameters against the real system to ensure that the initial values are appropriate (Bala et al., 2017). Model parameter verification is done by validating the values that are used for the parameters by using existing knowledge and reliable parameter sources (Qudrat-Ullah, 2005). To ensure that the model is robust under different conditions, the extreme condition test evaluates the validity of the equations by assessing if the model reacts as expected by the real system. For example, if the real system is expected to decrease production, the model should also decrease production. The boundary adequacy test ensures that all necessary structural relationships are present to achieve the model purpose, by checking if any additional feedback loop with significant impact was omitted (Bala et al., 2017). This test is done during the causal loop development phase by looking at all the variables and determining if they have an impact on the dynamic hypothesis and purpose. The test would start with the problem that is addressed by the model, like limited raw material, and an exogenous variable. If no clear hypothesis or reason for a link between the problem and variable can be identified, the boundary test is satisfied and the variable does not have to be included. If, however, a plausible hypothesis for including the variable and link can be found, the model needs to be expanded to include the variable as an endogenous variable (Qudrat-Ullah, 2005). The dimensional consistency test ensures that the units of measures and variables are the same on both sides of the equation, and is executed with a built-in function included in most system dynamic modelling software (Bala et al., 2017).

The model behaviour test is classified by the behaviour reproduction, behaviour anomaly and behaviour sensitivity test. The behaviour reproduction test determines how accurately the model behaviour represents the real system behaviour. The coefficient of determination (R-square) is the most common approach to measure the fit of the model. When a model's behaviour contradicts the real system behaviour, the model may have defects. The behaviour anomaly test critically reviews each loop in the model and removes any loop that is creating implausible behaviour or defects. This is done during the iterative approach when developing the model and comparing it to historical data. Behaviour sensitivity detects which small changes have big impacts on the model. The fewer parameters with such characteristics, the more credible the model (Bala et al., 2017).

There are multiple other behaviour tests (Forrester and Senge, 1979), however, Sterman (2000b), suggests a structural assessment (to check if the structure of the model is consistent with the real-life components, variables and parameters), model boundary adequacy evaluation (to ensure that all key elements are included in the model), structural behaviour test (ensure that the model generates logical behaviour), dimension consistency evaluation (check model units) and extreme conditions test (to assess if key parameters generate realistic outputs). These tests were also conducted in the system dynamic model of Iran's farming industry (Bastan et al., 2016). According to an article by Pejić-Bach and Čerić (2007) that listed and discussed the most important steps in system dynamic model development, the most important evaluation tests are the dimensional consistency test, extreme condition test and behaviour sensibility test. However, the most important overall validation test is the historic fit test, which ensures that the model accurately represents the historic occurrences and data (Sterman, 1992)

5. **Policy Formulation and Evaluation:** Finally, scenarios are imposed on the validated, verified and tested model. The output generated by the scenarios is analysed and interpreted for decision-making. The scenarios often represent different policy decisions but can be any situation that requires further understanding, like limited seed availability. Scenarios are also often optimisation-driven to determine the best possible outcome (as further discussed in Section 2.2.3). The parameters used to analyse the scenarios vary per project and can range from the area under production, water level (Bastan et al., 2016), price coefficient, revenue, consumer surplus (Rich and Dizyee, 2016), to sales and cash levels (Oleghe, 2020). The parameters for analysis for this project include cost, price, volume and most importantly net income, and are discussed further in Section 2.3.1.

Martinez-Moyano and Richardson (2013) conducted interviews with system dynamic experts to identify system dynamic best practices. The determined best practices included identifying the reference model under question (namely the Tanzanian sunflower industry), developing the dynamic hypothesis of how the system reacts, testing extreme conditions while formulating the model equations to ensure that the system reacts as it should, and ensuring dimensional consistency in all equations. The study further specified that an enormous amount of exploring remains to identify the most important best practices.

2.2.3 System Dynamics and Optimisation

Policy formulation and evaluation, step five in the system dynamic analysis approach (Section 2.2.2), may include “upgrading” or ”improving” a value chain into an ideal state. Thus optimising the value chain to perform at its best. By optimising a value chain system, decision-makers can see where the problem areas lie, and which node requires attention to increase overall value chain profitability. Optimisation models can potentially improve policy analysis and design by improving the speed and power of formal analysis models (Coyle, 1985).

Optimisation has been used in combination with system dynamics to identify the best range or combination of parameters for a fixed environment. The optimisation results have been used to maximise or minimise functions within a system dynamic model (Duggan, 2008). System dynamics has been combined with optimisation models as discussed by Ruth and Hannon (1997) for a variety of problems, like optimising traffic flows, the behaviour of a firm for economic optimisation, the optimum resource allocation between two products that use the same raw materials, optimising the use of non-renewable resources, and the optimal for harvesting fish. Most applications have the goal of combining dynamic engineering representations with accounting models to economically optimise processes (Ruth and Hannon, 1997).

More recent examples of combining system dynamics with optimisation include redesigning the primary healthcare centres in terms of geographical location and service delivery allocation (Mitropoulos et al., 2023), modelling the access to specialist care and services to improve mental health care (Vacher et al., 2023). Furthermore, optimising the curving dynamics (more specifically the suspension parameter) of an articulated monorail vehicle with a genetic algorithm (Jiang et al., 2020), and optimising investment cost for predicting maintenance with a cost-benefit analysis (Meng et al., 2022).

To improve the production and profitability of New Zealand sheep farming a bio-economic system dynamic model was developed, which could be used to inform decision-making by farmers. The model was used to investigate the change in ewe flock and flock wastage rates, while maximising the meat breed sire use. The model captured the cash operating surplus and net present value of the whole farm (Farrell, 2020).

The dynamics of producers increasing their production when prices increase, which in turn decreases prices, as well as consumers increasing their purchases as prices decrease, was studied with a system dynamic model that attempted to find the optimum size of a company to maximise profit, given these market dynamics. Ruth and Hannon (1997) developed the system dynamic model of the company and included a demand curve that created the inverse relationship between price and demand. The demand curve impacted the selling price which was used in the profit calculation. The trade-off between volume and price became very clear and could be studied in detail, as is required for the Tanzanian sunflower value chain. Combining system dynamics and optimisation, as done in the example of the optimum company size by Ruth and Hannon (1997), allows the researcher to conduct multiple experiments and answer different optimisation questions and then immediately illustrate the impact of the solved optimum on the modelled system.

An optimum system dynamic model was created for a non-renewable resource. The model aimed to find a path through time, for extracting oil from an oil refinery. The refinery had a dynamic problem, seeing that if all the oil was extracted immediately, the profits could be invested somewhere else and grow with interest. While if one would wait to extract the oil, the oil price could increase (due to a limited supply of oil) giving larger profits after a period of time. However, the overhead costs would still have to be incurred, hence the optimum seemed to be between one of the two options. Similarly, for sunflower seed processors, processing the maximum amount of seed available, will drive down overhead costs and supply the maximum amount of revenue. However, high demand for seed will increase the seed price (due to supply and demand dynamics), increasing costs. To solve the oil extraction problem, numerical and analytical techniques were combined to find the optimum path of the oil volumes extracted. The model maximises the cumulative current value of profits over time while ensuring that no more oil is extracted than available. The profits were discounted to calculate the net present value, which accounted for profits that occur dynamically at different time periods (Ruth and

Hannon, 1997). Because the resource pool of the Tanzanian sunflower value chain (sunflower seed) is not limited, it is not important to include the net present value.

AnyLogic has many examples that include steps to develop different types of models. The AnyLogic website provides step-by-step instructions to develop the bass diffusion model, a well-known system dynamic model of a product's life cycle. The model illustrates the adoption of a product due to formal advertising and word-of-mouth advertising, which results in potential product purchases. AnyLogic expands on this model, by creating an optimisation experiment that optimises the marketing strategy, by minimising the cost of advertising to meet the required number of purchases. The experiment added the objective to minimise the total expenditure as the objective function and set the advertising expenditure as the varying parameter in the experiment properties. The experiment also specified the minimum amount of purchases required, the time period to achieve the required purchases, and the maximum limit of the varying advertising expenditure parameter. To find the optimum total expenditure, AnyLogic iterated 500 times through different advertising expenditure levels while remaining under the maximum cost and ensuring a minimum amount of purchases after a specified time period (AnyLogic, 2023).

Finding the optimum seed purchases for the Tanzanian sunflower processors to maximise the entire value chain net income, is similar to the optimisation scenario, as it is also an additional analysis of the system dynamic model, similar to the bass diffusion optimum marketing strategy. The optimisation scenario wants to maximise net income, while the bass diffusion model minimises cost, and where the bass diffusion model has limited advertising expenditure, the Tanzanian sunflower processors have limited processing capacity. Given the many similarities, the approach executed by AnyLogic (2023) is applicable to optimise the Tanzanian sunflower value chain net income.

2.3 Value Chain Performance and Financial Sustainability

A brief analysis of value chain performance and sustainability indicators is conducted in this section. Firstly, some value chain performance measures are discussed, and then sustainability measures are reviewed, before focusing on financial-specific sustainability indicators. Finally, an overview of the selected financial sustainability indicator, net income, is provided.

2.3.1 Value Chain Performance Measures

The value chain's performance and financial sustainability need to be measured for impact measurement and scenario comparison. It is crucial to develop quantitative sustainability measures for legislative measure development (Senanayake, 1991). Value chain performance can range from financial aspects like profitability to non-financial outcomes like product quantity and quality, and process efficiency and flexibility (Kaplinsky et al., 2011). A literature review conducted by Gunasekaran et al. (2001) illustrated that there was a shift from focusing on traditional cost accounting performance measures to techniques that include customer service, asset utilisation, productivity and quality, which covered the entire supply chain performance, as opposed to only one node individually.

As agricultural value chain-specific performance measures, as required for the agricultural sunflower value chain, are still quite scarce in the literature, Aramyan et al. (2007) focused on evaluating a conceptual model that specified efficiency, flexibility, responsiveness and food quality as key performance measures. Efficiency is a very important performance indicator of a supply chain and its nodes (Bunte et al., 1998), and may include indicators like costs, profit and return on investment. Aramyan et al. (2007) illustrated that the most important indicators included costs and profits. These indicators were also included in an analysis of different crops' financial performance, together with the return on investment, net present values, profitability, benefit-cost ratios, break-even points and revenues. Crowder and Reganold (2015) indicated that financial indicators contribute to the analysis of competitiveness and sustainability of a value chain, as is the focal point for this study.

Sustainability Measures

Sustainability is the management of natural, technological, financial and institutional resources to ensure current and future human needs requirements (Valenti et al., 2011). Sustainable agriculture refers to social, ecological and economic sustainability. Economic sustainability is very similar to financial sustainability, as the goal of both is to estimate the net benefit of a project, based on the difference between the without-project and with-project scenarios, which differ between developed and developing countries. For developed countries, agriculture sustainability refers to diversification and environmental satisfaction, while developing countries, like Tanzania, mostly see sustainability as maintaining food production and preserving resources, of which one important aspect is profitability and efficient production (Bowers, 1995).

Zhen and Routray (2003) conducted a literature review to analyse the effectiveness of agricultural sustainability indicators in developing countries over the past fifteen years. The article stipulated important operational, social and economic indicators. The proposed operational indicators are very industry- and node-specific, and include amounts of fertiliser, pesticide and water use, soil nutrient content, depth of groundwater table, water use efficiency, quality of groundwater and nitrate content. While the social indicators encompassed food self-sufficiency, equality in income and food distribution, access to resources and support, and conservation knowledge and awareness of farmers (Zhen and Routray, 2003). These indicators are very specific for the producing node in the value chain and do not provide a high-level overview of the value chain sustainability state, as required for this study. Hence the operational and social indicators are irrelevant. However, focusing only on financial indicators may be limiting and fail to capture comprehensive agricultural sustainability by excluding key indicators. Yet, the project's focus on financial sustainability assists in narrowing the study and prevents the analysis from becoming cluttered.

Financial Sustainability Measures

The recommended financial indicators by Zhen and Routray (2003) included crop productivity, the benefit-cost ratio of production, per capita food grain production, and net farm income. However, crop productivity is only relevant to the seed producer node of the Tanzanian sunflower industry (and not for the entire value chain), and the ”per capita food grain production” reflects food self-sufficiency which relates back to social sustainability (not financial sustainability), and the benefit-cost ratio is more applicable for investment analysis than sustainability analysis. Hence, net income (expanded from net farm income to represent all nodes in the value chain) is the most relevant indicator for this specific project (Zhen and Routray, 2003).

Economic or financial sustainability illustrates capital efficiency and sufficient wealth generation by activities to keep producers in their field of work. For big investments, well-known economic feasibility indicators like internal rate of return, benefit-cost ratio and payback period are suitable. However, for smaller family-owned businesses, like farming, it is crucial to know if the activity (like producing sunflowers) can support the producer and his family. Indicators for smaller businesses may include traditional indicators of economic feasibility (internal rate of return, benefit-cost ratio and payback period), but are more likely to include net income, the proportion of the invested capital generated by the activity, minimum enterprise size and net income to the initial investment (Valenti et al., 2011).

Given that this project does not investigate the impact of an investment, the proportion of the invested capital generated by the activity and the net income to initial investment indicators are irrelevant. The “minimum enterprise size” indicator is similar to a break-even point, where the required units to make a profit are found. This indicator is however difficult to compare between different nodes and does not indicate a clear ”good” or ”bad” situation, as the “net income” indicator does, where one knows that the negative is bad and the positive is good. Hence, net income is the most relevant indicator for this specific project.

On the other hand, one could look at the raw material procured at each node as the investment cost, which would then allow the “proportion of the invested capital generated by the activity”, “minimum enterprise size” and “net income to initial investment indicators” (Valenti et al., 2011), as well as the ”benefit-cost ratio” (Zhen and Routray, 2003) to be relevant indicators. However, these indicators are usually calculated after the net income, each providing more insight from different perspectives. Furthermore, the indicators entail different challenges and data requirements to be calculated, which are not always available, making execution more difficult.

Even though many indicators may be used and very successful in analysing the financial sustainability of an agricultural value chain, net income (or profitability) has been mentioned in most of the literature discussed above and has been identified as the most appropriate indicator due to its wide application and ease of implementation. For ease of analysis and to avoid cluttering, it is proposed that only one indicator be used to analyse and compare the scenarios. Furthermore, the required data for the net income indicator is available for the Tanzanian sunflower industry. Finally, Smith and McDonald (1998) also supports this by stating that profitability indicators like production and net income are the primary agriculture sustainability indicators.

Net Income

Net income is discussed as important in Section 2.3.1 by Aramyan et al. (2007); Bowers (1995); Crowder and Reganold (2015); Valenti et al. (2011); Zhen and Routray (2003). In 1937 Smith noted the importance of accurately measuring and reporting the financial performance of businesses, and Graham and Meredith (1937) emphasised the importance of analysing net income as a key indicator of a company's profitability and financial sustainability.

Net income is calculated by subtracting the total expenses (including tax) from the total revenues. A positive net income is known as a profit, while a negative income is a loss. Net income takes into account all products sold and all expenses to produce the products. It considers direct and indirect overhead costs, while a gross margin only considers the direct costs of goods sold (Muprhy, Chris, 2023; Weil et al., 2013). Net income is a function of price, cost and volume.

Price: Crop prices, and thus sunflower prices, are influenced by supply and demand, which can be influenced by multiple factors like world prices, the world collecting volumes and the exchange rate on the demand side, as well as supply being influenced by area, climate and input costs (Aleksandrova and Mel'nikova, 2016). The sunflower seed, oil and cake prices are crucial for this project to analyse their change, and impact on production and ultimately to calculate the net income of each node in the Tanzanian sunflower value chain.

Cost: The Supply Chain Operations Reference (SCOR) model is an industrial standard for supply chain management that has been generalised and used across many industries and value chains. The model describes the business activities, tasks and operations to satisfy internal and external customer demands. It analyses the supply chain's reliability, responsiveness, flexibility, cost and asset management, in terms of its plan, source, make, deliver and return processes. SCOR also looks at the relationship between performance metrics (Supply Chain Council, 2012). The SCOR model was selected by Weerabahu and Nanayakkara (2019) as a reference model in a study that determined how supply chain planning and good sourcing can improve an agricultural rice supply chain in Sri Lanka, due to its efficiency focus. The article tried to increase competitiveness by reducing supply chain gaps. A survey was conducted to determine the key processes and strategies relevant to the SCOR model's planning and sourcing areas, where cost was selected as the most important performance attribute (Weerabahu and Nanayakkara, 2019).

The cost in this project refers to the expenses incurred to produce sunflower seed, the expenses to process sunflower seed into oil and cake, and the expenses incurred to transport seed, oil and cake from producer to processor.

Volume: Costs are related to utilisation. Utilisation expresses the extent to which capacity is being used, by illustrating the relationship between actual output and potential output volumes (Adeyemi and Olufemi, 2016). Capacity is defined as the maximum potential volume that can be produced given the available resources (Okunade, 2018). The under-utilisation of a processing facility will increase the operating cost (Seguin and Sweetland, 2014), and an increase in capacity utilisation means a decrease in the cost of production (Afroz and Kumar Roy, 1976). Thus, each firm determines its utilisation level goal to minimise cost (Nikiforos, 2013). Due to the big impact that utilisation can have on costs, it is important to track output volume together with the costs and prices of each node in the Tanzanian sunflower value chain.

According to a survey conducted by Gunasekaran et al. (2004) investigating supply chain performance measures "percentage of defects" is the most important performance rating for the processing node. However, "cost of operation hour" and "capacity utilisation" are also very important. These two indicators are resource efficiency measures. If these two indicators have a good performance score, it generally means that the unit cost is lower. For a value chain that needs to be optimised, operational efficiency is very important for all supply chain partners (Gunasekaran et al., 2004). Hence, cost and utilisation should be tracked when analysing a value chain to be improved.

2.4 Literature Review Conclusion

Different methods to analyse entire value chains exist, but there seems to be a gap in the literature on representing the entire value chain in a model that incorporates the dynamics of the value chain and how the different nodes and their financial sustainability affect each other, and not just focus on one single node at a time per model. System dynamics was selected because of its ability to analyse and simulate complex adaptive systems, its application in the agricultural industry and its suitability to the problem. System dynamics increases the understanding of change by analysing the interactions between components and helps to identify unexpected or unspecified outcomes of a decision. The literature review also discussed the system dynamics execution steps and examples where the approach has been applied to the agricultural industry, as well as where system dynamics has been combined with optimisation models to find an ideal state of a system.

From the literature review, it seems that conducting optimisation studies in agricultural value chains has been applied in limited cases, and optimising an entire agricultural value chain has not been conducted before (to the best of the researcher's knowledge), as most optimisation research focused on improving one node of the agricultural value chain.

Because financial indicators are so successful in illustrating the competitiveness and sustainability of a value chain, the literature study identified key financial sustainability indicators for value chain performance measurement and comparison between the project's scenarios. According to the literature, net income is a primary agriculture sustainability indicator, crucial to tracking value chain performance and widely and easily applied. Furthermore, indicators need to be tracked for each node in the value chain to be able to understand the total value chain impact.

Tanzanian Sunflower System Dynamic Model Development

This chapter develops the Tanzanian sunflower value chain system dynamic model as researched and recommended in the literature review (Chapter 2), with the steps proposed by Sterman (2000a). Firstly, the problem and its background are discussed in Section 3.1, then the dynamic hypothesis with the causal loop diagram is developed in Section 3.2, after which the model is developed in AnyLogic with the mathematical formulation (Section 3.3), and finally the model is verified and validated in Section 3.4. This entire process was executed in an iterative process of going back and forth between the problem dynamic hypothesis, causal loop diagram, mathematical formulation, and validation and verification until the model represented the real Tanzanian sunflower value chain system accurately.

3.1 Background and Problem Definition

The first step of the model development was to understand the problem and its background and environment to articulate the problem and the study's objective as well as the system dynamic model boundary (Bala et al., 2017). This section gives a brief overview of the global edible oil industry, as well as the Tanzanian sunflower value chain, before discussing and defining the problem, the study's objective and the model's boundary in more detail.

3.1.1 Problem Environment

Global Sunflower Industry Overview

Edible oil is the main market for oilseeds, like Tanzania. The global edible oil market is segmented into multiple edible oil variants but is dominated by palm and soybean oil, the two most affordable options. The global production shares of the key edible oil variants are depicted in Figure 3.1, which shows that sunflower oil production constitutes roughly 10% of the total global production of major edible oils.

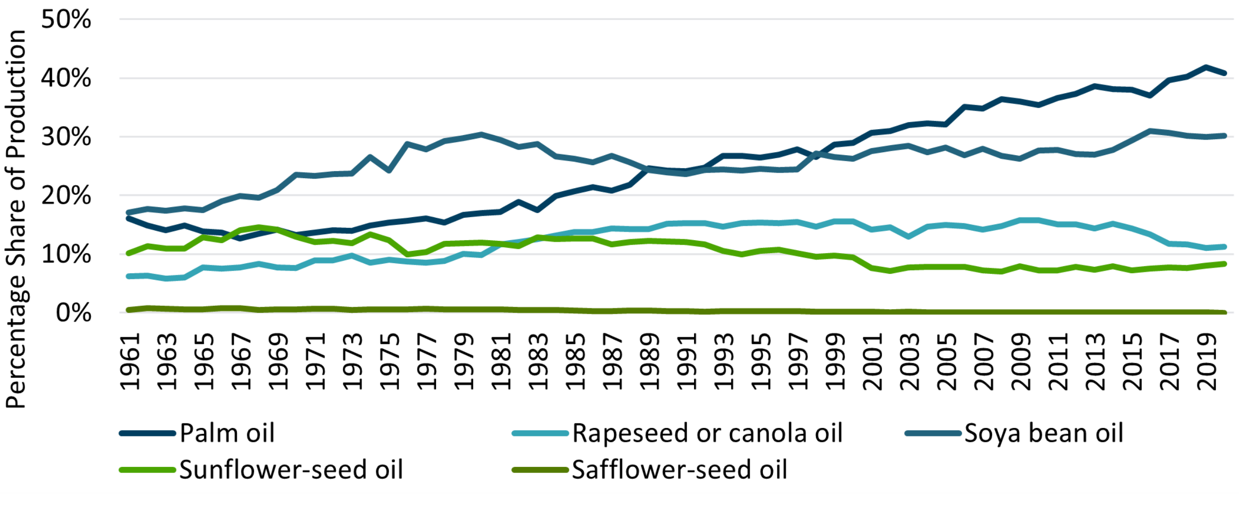

Figure 3.1: Global Edible Oil Production Shares from 1961 to 2020

Source:(FAOSTAT, 2022)

The palm oil segment reflects consistent growth since the early 1980s and accounts for close to 40% of global production volumes among the major edible oil alternatives depicted in Figure 3.1. Palm oil is regarded as the most affordable oil and is preferred in fried food with a well-established global supply chain that contributes to the growth in market share. However, increases in disposable income and preference for healthier and more sustainable edible oil options such as sunflower, olive and canola oil have influenced the shifting market trend (Meyer, 2017). Of the several edible oils, sunflower is a fast-growing industry in Tanzania, contributing about 36% to the national cooking oil requirements in 2022 (BFAP, 2022; FAOSTAT, 2022; ITC Trade Map, 2022).

European producing countries constitute more than 75% of sunflower oil production and just more than 70% of total sunflower seed production (FAOSTAT, 2022). According to the latest Food and Agriculture Organization data (2022), the largest global producers of sunflower seeds are Ukraine (27%) and the Russian Federation (25%), while African countries collectively produce only around 5% of global sunflower seeds. The global sunflower seed production composition for 2022 is depicted in Figure 3.2. In Africa, Tanzania is the largest sunflower seed producer, accounting for 45% of the continent's total production, followed by South Africa with 29% (FAOSTAT, 2022).

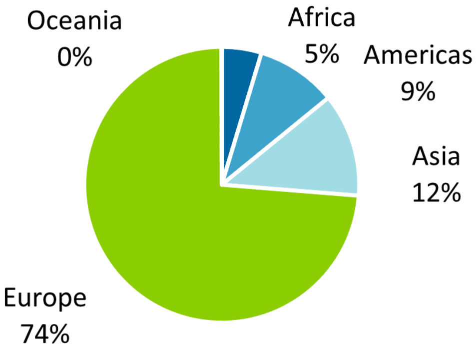

Figure 3.2: World Sunflower Production Composition in 2022

Source: (FAOSTAT, 2022)

Tanzanian Sunflower Value Chain Overview

Figure 3.3 illustrates the volume flow of the sunflower value chain in Tanzania for 2022, which was developed from basic value chain structures from Van der Vorst et al. (2007) and Van Zyl (2010), and ground-truthed data gathered in Tanzania (BFAP, 2022).

Sunflower is planted around January (depending on weather conditions) and is harvested from July to September in Tanzania. The crop is very drought resistant but subject to many uncontrollable external factors that affect the yield and total production (Enrique et al., 2015). Sunflower is mainly produced by small-holder farmers who still use old production methods that are inefficient and subject to even more variability in production volumes.

Processors buy the seed and store it in silos until it is processed. This may, however, entail seed being stored for up to a year until it is processed, to maintain continuous processing by sunflower seed processors. At harvest time, the sunflower seed is usually the cheapest due to the high supply, and the price increases gradually again afterwards.

Sunflower seed is processed by processors, who crush the seed to extract the oil. The oil is refined and sold for human consumption, while the by-product, sunflower cake, is sold to local feed mills or exported for animal feed. All processors in Tanzania, irrespective of their processing capacity, were found to have a capacity utilization below 50% with the under-supply of crushing seed being the leading factor (BFAP, 2022).

Seed aggregators trade some of the seed to get the seed from the producers to the processors. There is barely any seed imported and exported because imported and processed seed cannot compete with imported low-priced palm oil (BFAP, 2022; ITC Trade Map, 2022). Some small volumes of crude oil and cake are also traded by aggregators, moving the locally produced product from processors to market.

Traders do not add any value besides transporting the product and have been reported to follow a margin percentage strategy (always adding a percentage to their purchase price, to obtain their profit on their selling price). To meet the local oil demand, refined oil (mainly palm oil) is imported (ITC Trade Map, 2022).

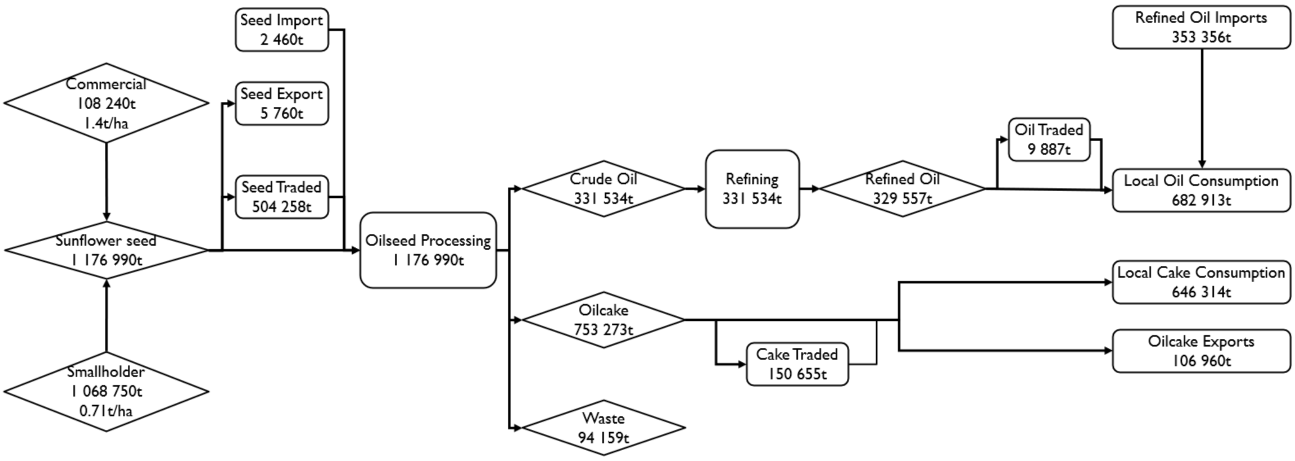

Figure 3.3: Tanzanian Sunflower Value Chain Volume Flow in 2022

3.1.2 Problem Articulation and Objective

Figure 3.3 illustrates the volume flow of the sunflower value chain in Tanzania for 2022, however, in 2021 the seed volumes were much lower, as depicted in Figure 3.4, illustrating the sunflower production (volume, area and yield), consumption and trade. This is the reality for the Tanzanian sunflower industry. Due to a highly variable environment, sunflower production is very volatile. The available sunflower seed can vary from 1.5 million tons to 2 million tons from one year to the next, creating uncertainty for processors if they will obtain sufficient local seed to process and at what price.

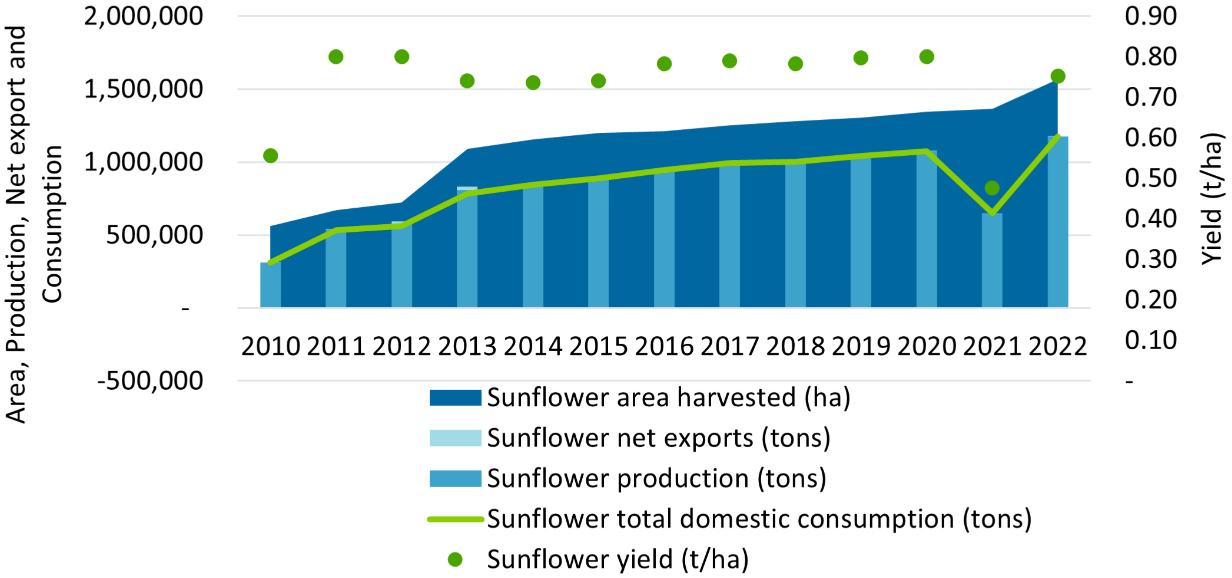

Figure 3.4: Tanzanian Sunflower Industry Production, Trade and Consumption

Source: (BFAP, 2022; FAOSTAT, 2022; ITC Trade Map, 2022; Tanzania Ministry of Agriculture, 2022)

Figure 3.5 illustrates the 2022 net income per node for the sunflower industry (taking into account the cost, price and volume of each specific node). Overall, the value chain is relatively healthy, with all major nodes making a profit. Traders make a lower margin because they merely move the raw material or product and do not make any changes to the product that add value. Processors make the highest profit, yet in 2021 (where less local sunflower seed was available) the processor profitability may have been less desirable. In-country reports indicate that processors are under strain due to the high international seed and oil prices, as well as low utilisation levels, and that limited processors are present in Tanzania (BFAP, 2022). In the Tanzanian sunflower value chain, the processing node is the most commercialised node, which generally means that the node has high overhead and fixed costs.

Additionally, Figure 3.5 illustrates the profit per node if the volume that passes through each node decreases by 20% and 40%. The data labels indicate the percentage change in net income when comparing the net income at 100% utilisation to the net income with 80% and 60% utilisation. For example, the profit for producers when only 60% of their capacity is utilised is 56% lower than when 100% of their processing capacity is used. For the trader nodes, the effect is equivalent to the loss in volume (20% or 40%), as they have limited fixed overhead costs. However, the producer and processing nodes have higher reductions because they have fixed overhead costs that need to be covered by the remaining volumes. The net income for producers when 20% less seed is produced is 25% lower than when 100% of their processing capacity is used, and processor net income is 22% lower.

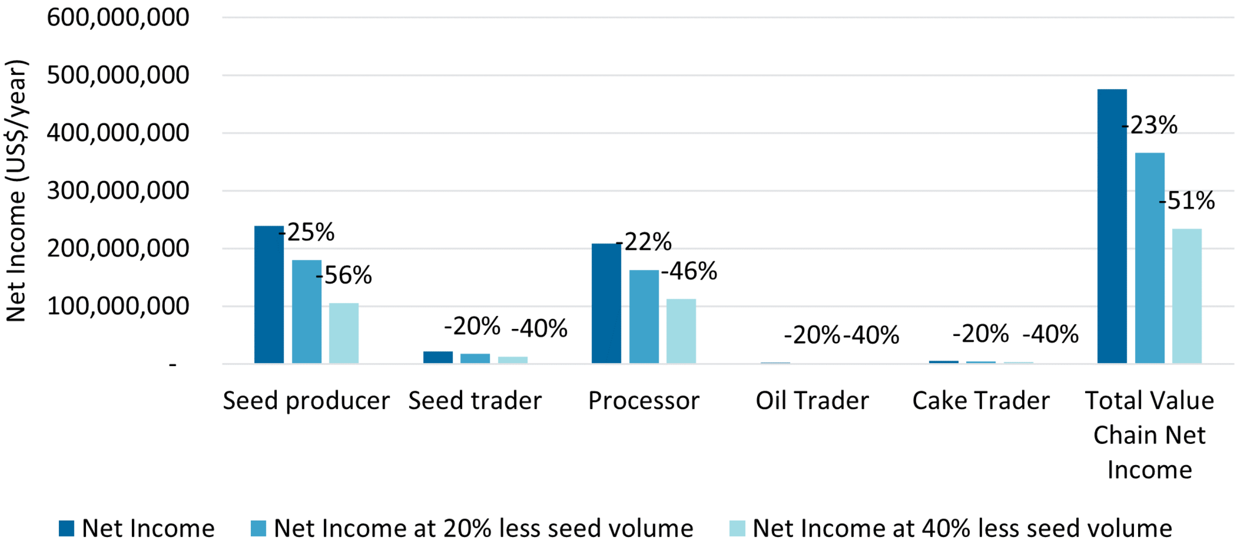

Figure 3.5: Net Income per Node at Different Volume Levels

Source: (BFAP, 2022; ITC Trade Map, 2022; Tanzania Ministry of Agriculture, 2022)

This effect needs to be unpacked in more detail, taking into account additional effects like prices and costs due to a change in available seed volumes. It is the objective of the project to model the feedback and relationships of the value chain system boundary (depicted in Figure 3.3) over a projected 10 years. The project objective is to analyse the impact of different raw material availability levels and sources (local or imported seed) on the entire Tanzanian sunflower value chain financial sustainability.

The dynamic system feedbacks are expected to make the system react differently to what is calculated in the high-level analysis in Figure 3.5, when accounting for dynamic changes around price, volume and cost. The industry is represented by a system dynamic model, to ensure that the entire value chain is considered and that every feedback, effect and consequence is considered and captured.

3.1.3 System Dynamic Boundary Selection

The system boundary refers to the limited causalities included that explain the observed problematic behaviour (Martinez-Moyano and Richardson, 2013). The boundary of the system under investigation only considers the factors directly related to the Tanzanian sunflower value chain, as illustrated in Figure 3.3, as these are the crucial building blocks of the industry and are dependent on the variables within the model.

The model starts in 2022, as the most recent and validated data was gathered in 2022. The value chain is modelled over 10 years to obtain a good feeling of what the future may hold, and given that nothing can be done to change the past. The model does not project further into the future, as data availability is limited and a longer time horizon may yield unreliable results. Furthermore, a ten-year projected time frame is a common time frame for agricultural forecasting (OECD, 2023). The model runs monthly, to get a good understanding of the cyclic nature of the volumes and prices that are realised due to the annual harvest cycle (seed being harvested only during three months of the year). Furthermore, running the model monthly assists in validating the model's cyclic behaviour and provides the potential to analyse more detailed scenarios (separate from this study) and zoom into a specific time frame as the industry differs significantly at different times of the year due to the production cycles.

Because the research question is more high-level, focusing on the impact of seed availability on the entire value chain, the scenarios are analysed on an annual basis and cover the entire ten years for ease of comparison. As discussed in the literature review (Section 2.3), the scenarios are analysed and compared with the net income financial feasibility indicator, which is tracked and assessed at each node and across the entire value chain for each month and year and over the ten years in US dollars.

3.2 Dynamic Hypothesis and Causal Loop Diagram

The dynamic hypothesis is a theory of the Tanzanian sunflower value chain system behaviour. It aims to develop an endogenous explanation of the system and seeks to define the important feedback loops that drive the system (Bala et al., 2017). The relationships in the Tanzanian sunflower value chain are represented, specifically focusing on prices, production, demand, stocks and trade volumes for seed, oil and cake.

The price, cost and volume dynamics of the Tanzanian sunflower value chain are hypothesised to generate the observed seed supply dynamics in the simulation model and depicted in the causal loop diagram in Figure 3.7.

3.2.1 Dynamic Hypothesis

The main hypothesis is illustrated in Figure 3.6 and assumes that the higher the available seed supply, the lower the overhead costs per ton of seed processed, and the more profitable are processors (the black link on Figure 3.6). Due to the economy of scale principle (Smith, 2010), processors can split their overhead costs over more processed volumes and are thus able to produce oil for cheaper, and make a higher net income with more raw material seed due to lower costs and higher revenue (more volumes sold).

Furthermore, because processors can operate more sustainably, it is hypothesised that an increase in processor profitability will increase the seed demand, which provides seed producers with a reliable local seed market. Additionally, due to supply and demand dynamics (Smith, 2010), higher demand for seed will increase the seed price, increasing the seed production (indicated as the blue link in Figure 3.6).

The goal is to quantify the impact that a reliable seed supply and an unreliable seed supply (which makes the seed demand reliable or unreliable as it influences the processor's profitability and sustainability) have on the value chain's financial sustainability. These relationships, with their full system feedback loops, are further illustrated and discussed in Section 3.2.2, discussing the causal loop diagram.

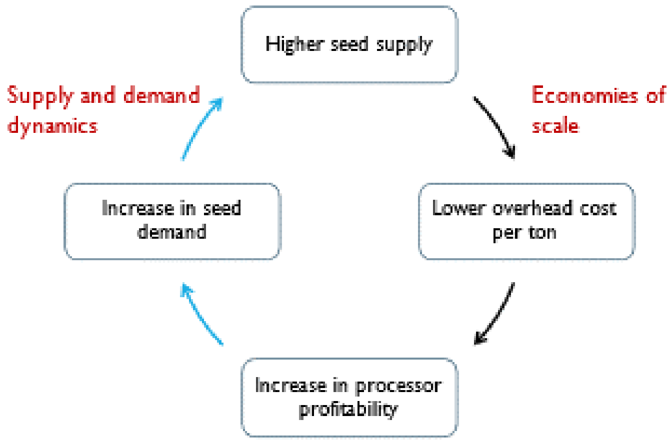

Figure 3.6: Dynamic Hypothesis Visualisation

3.2.2 Causal Loop Diagram

The most common approach to explain a model structure is to base the model on a causal loop diagram. Furthermore, the generic structure approach is very handy as generic structures (like a value chain) can be applied to a specific problem (Pejić-Bach and Čerić, 2007).

The causal loop diagram, also called the cause-and-effect diagram, describes the feedback loops of the system, and is illustrated in Figure 3.7. The causal loop diagram was developed by starting with a hypothesis of the system (illustrated in Figure 3.6) in combination with the value chain structure illustrated in Figure 3.3, supply and demand principles (Smith, 2010), a basic crop partial equilibrium model as illustrated by Simchi-Levi et al. (2014), as well as the International Model for Policy Analysis of Agricultural Commodities and Trade Model developed by Rosegrant et al. (2008), and referring to the Tanzanian sunflower partial equilibrium model developed by BFAP (2022). The causal loop diagram was developed within the iterative approach of going back and forth between the causal loop diagram, model formulation and validation and verification steps of the system dynamics approach until the model represented the reality and passed the verification and validation, as discussed in Section 3.4.

Figure 3.7 illustrates the causal loop of the project and the Tanzanian sunflower value chain. The positive and negative signs on the links indicate whether the impact of one variable is positive or negative on the following affected variable. The bold green feedback loops represent the main dynamic hypothesis illustrated in Figure 3.6. Higher volume of seed processed (”Seed demand” and ”Processing” in Figure 3.7) increases processor utilisation, which decreases processing costs and increases the gross margin and net income. This increases the seed demand, which in turn increases the area under production which increases seed production, or seed supply.

There is no direct link between seed production and processor cost of production (as indicated in Figure 3.6). Instead, an increase in seed production decreases the local seed price, which allows processors to produce oil at a lower price (as seed can be purchased at a lower cost), which improves the processor’s gross margin and profitability.

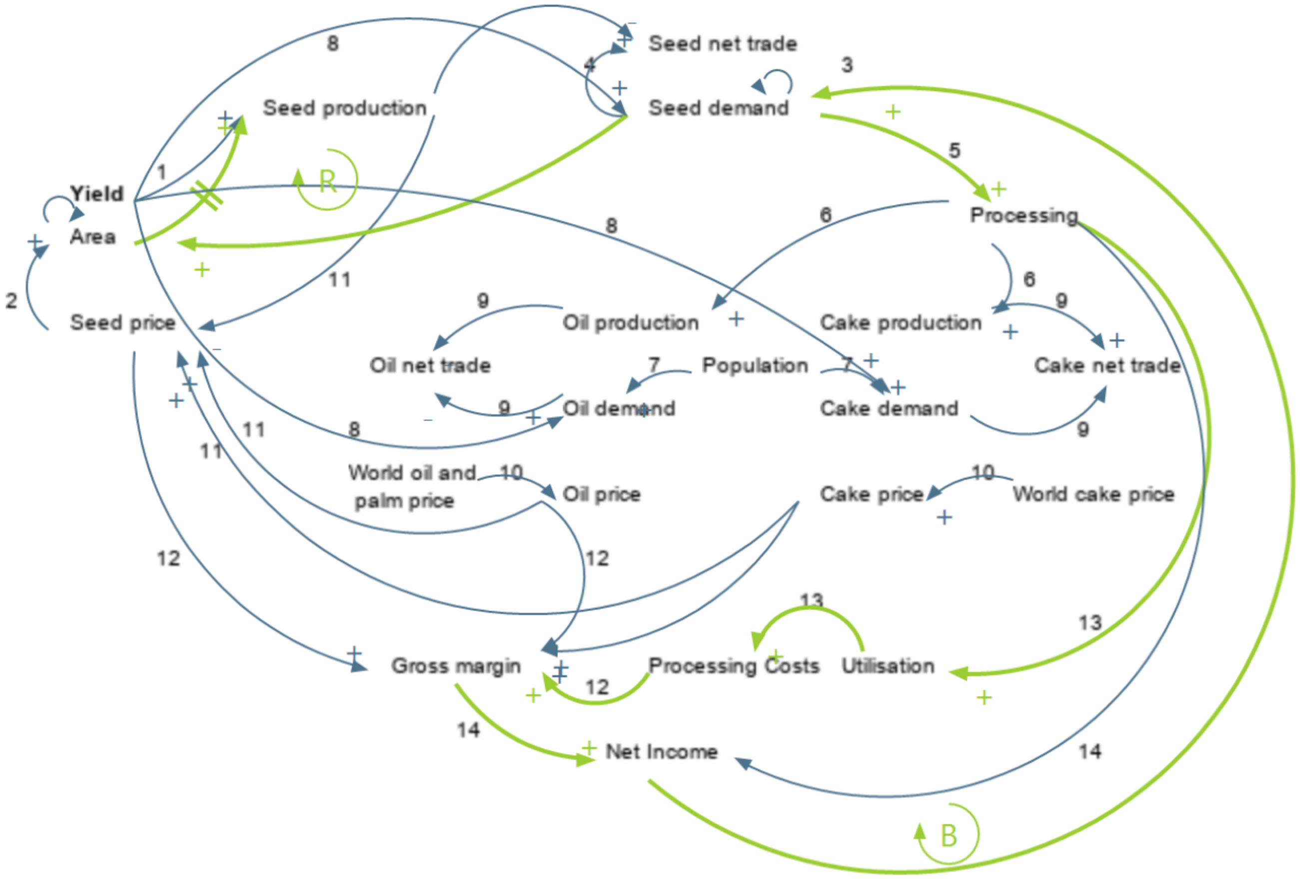

Figure 3.7: Causal Loop Diagram

The causal relationship links illustrated in Figure 3.7 above are explained as follows:

1. Seed is produced given a specific area under production and yield realised in that area (Rosegrant et al., 2008). The area has a delay (noted by the two lines on the link), as production only occurs once a year when the crop is harvested over roughly two months.

2. The area of seed produced is dependent on the historic sunflower area produced, as well as the seed price (Simchi-Levi et al., 2014), as the higher the seed price, the more profitable the seed producers are, and the more hectares producers will plant to increase their seed production and profit.

3. Seed demand depends on the processor's net income (the more profitable processors are, the higher the seed demand will be, as also explained in the dynamic hypothesis Section 3.2.1), as well as historic seed demand.

4. The balance between seed demand and locally produced seed is the net trade of seed (Rosegrant et al., 2008). The Tanzanian net trade of seed has historically mainly been seed imports due to insufficient local seed volumes but has been very limited due to the high imported seed prices.

5. The volumes processed are equal to the seed demand. Splitting seed demand and processed seed provides an opportunity to specify the volumes that are crushed or used for another purpose. However, other uses in Tanzania are insignificantly small, and thus it is modelled that the same volumes flow through both nodes in the model.

6. Processors produce oil and cake according to the extraction rates realised in Tanzania (BFAP, 2022).

7. The demand for oil and cake is influenced by the population growth of Tanzania (Simchi-Levi et al., 2014). The higher the population, the higher the oil and cake consumption. The model

excludes the impact of consumer trends on demand. For example, the trend where consumers prefer to eat sunflower oil instead of palm oil due to health reasons is excluded from this project.

8. Oil and cake demand also follows the trend of the sunflower yield, when the yield is higher, the oil and cake demand is also higher. This feedback loop is not a generic expected loop but can be explained due to a large amount of subsistence farming in developing countries, like Tanzania (Fan et al., 2013), as the producers consume their own product and will consume more if more is available after harvest.

9. The trade of oil and cake is also a balancing figure (as is the case for seed), assuming that the difference between production and consumption will either be imported or exported (Rosegrant et al., 2008). Tanzania has an insufficient supply of edible oil and has historically mostly imported oil, while the local cake market is quite informal and unestablished, forcing Tanzania to export the net cake thus far (ITC Trade Map, 2022).

10. The domestic prices of the two products are dependent on their world prices (Aleksandrova and Mel'nikova, 2016; Rosegrant et al., 2008). The local sunflower oil price is influenced by the international sunflower oil and palm oil price, and the local sunflower cake price is dependent on the international world cake price. The local prices do however not impact the world prices because Tanzania is currently a too small player in the global sunflower and edible oil market to affect the global prices.

11. The price of seed is dependent on the volume of the seed produced (if more seed is available, the price will decrease due to supply and demand dynamics (Smith, 2010)), and the sunflower oil and cake prices that drive the seed price up.

12. The seed price, product prices (oil and cake prices) and processing costs are used to calculate the gross margin of processors (Weil et al., 2013).

13. Utilisation is dependent on the volume of seed being processed, as it is defined as the amount of output divided by the potential output. Utilisation affects the processing costs, as the higher the utilisation, the lower the fixed costs because the costs are split between more volumes (Afroz and Kumar Roy, 1976).

14. The gross margin and processing volume are used to calculate the processor's net income (if positive: profit, if negative: loss) (Muprhy, Chris, 2023; Weil et al., 2013).

15. Finally, the net income influences the seed demand as mentioned in number 3.

Within the entire system, there is a positive feedback loop marked by a "B", from seed demand, to seed processed, to utilisation, to processing cost, to gross margin, to net income, and finally back to seed demand (link: 5-13-13-12-14-3). There is also a negative loop marked by "R", from area to seed production to seed price, and back to area (link: 1-11-2). In a positive feedback loop, a disturbance results in further change along the supply chain, while a negative feedback loop is goal-seeking, where the system seeks to return to its equilibrium after a disturbance (Sterman, 2000a). The positive and negative feedback loops play against each other and with each other to create the system's reaction, which is difficult to capture without a system dynamic model.

Boundary Adequacy Evaluation

Besides the discussed elements, the Tanzanian sunflower industry system is affected by many external factors like weather, production practices, labour cost and availability, consumer preference, government support, the Tanzanian economy and many more. These factors are excluded in this project's analysis and thus outside of the system boundary, as they are exogenous variables that are independent of the variables within the model (the variables inside the boundary do not affect these variables). They are further excluded because they do not relate to the problem statement and goal (Ruth and Hannon, 1997). For example, weather cannot be controlled or affected by any variable in the Tanzanian sunflower industry. Weather is however indirectly included through the yield input data, where the yield decreased in drought years for example. However, such weather fluctuations are excluded for the projected scenarios that simulate the future, as the weather is unknown. Labour cost depends on inflation, which is largely attributed to a country's economy. Even though the sunflower industry does contribute to the Tanzanian gross domestic product, it is too small with insufficient power to change Tanzania's overall economy. Consumer preferences are qualitative views on a product (like sunflower oil preference for health reasons), which can not be influenced by sunflower production or price (apart from the supply and demand dynamics which are included in the model, and actually not considered under consumer preferences), and production practices are mostly subject to the producer's own opinion. The government can not be controlled and not be influenced by the Tanzanian sunflower value chain. Given that these factors can not be affected by the Tanzanian sunflower industry system, they can be classified as exogenous variables, and do not need to be included in the model according to the boundary adequacy test (Qudrat-Ullah, 2005).

However, their effect can be modelled on the Tanzanian sunflower system dynamic model, for example by changing the yield (weather), increasing cost (labour cost), changing product demand (consumer preferences) and changing taxes (government support). The factor exclusion does not limit the outcome of the study, which is to illustrate the effect of the raw material supply of processors on the entire value chain sustainability. Furthermore, additional factors and variables can easily be researched and included to develop separate scenarios for a different question with a different goal.

Causal Loop Diagram Validation and Verification

The relationships defined in the causal loop diagram were further verified with a statistical analysis that determined the correlation and coefficient of determination (R-square) value of each link identified in the causal loop diagram, thus statistically supporting the feedback loops identified in Figure 3.7. The data used for the statistical analysis was validated as discussed in Section 3.4.1.

The correlations of the links between two variables as illustrated in Figure 3.7 were determined and listed in Table 3.1. For example, the correlation between yield and seed production was determined to be 97%, and the R-square value was calculated as 94%. Table 3.1 also specifies if the correlation and coefficient of determination indicate a relationship, thus if the correlation is above 80% or below -80%, and if the R-square value is above 70% (known to be statistically significant (Frost, 2019)). This was done for each link in the causal loop diagram. Hence, statistical analysis was used to validate the links identified in the causal loop diagram, to be able to conclude that one variable is affected by another variable and justify the link.

Table 3.1: Statistical Analysis of Causal Loop Links

Relationships		**Strength of relationship**				**Explanation**
Variable 1	**Variable 2**	**Correlation**		**R square**		
Yield	Seed production	97%	>80%	94%	>70%	
Area	Seed production	99%	>80%	97%	>70%	
Historic area	Area	94%	>80%	88%	>70%	
Seed price	Area	26%	<80%	7%	<70%	Area under production increases as profit (price) increases
Seed production	Seed price	-76%	<80%	58%	<70%	Supply and demand principals (price decreases as production increases)
Processor Net Income	Seed demand	86%	>80%	74%	>70%	
Seed production	Seed net trade	-93%	<80%	87%	>70%	Balancing figure: Net trade = Production - Demand
Seed demand	Seed net trade	-93%	<80%	86%	>70%	Balancing figure: Net trade = Production - Demand
Seed demand	Seed processed	98%	>80%	97%	>70%	
Seed demand	Area	98%	>80%	97%	>70%	
Seed processed	Oil production	99%	>80%	99%	>70%	
Seed processed	Cake production	99%	>80%	99%	>70%	
Oil production	Oil net trade	-80%	<80%	64%	<70%	Balancing figure: Net trade = Production - Demand
Oil demand	Oil net trade	-87%	<80%	75%	>70%	Balancing figure: Net trade = Production - Demand
Population	Oil demand	97%	>80%	95%	>70%	
Oil demand	Yield	95%	>80%	91%	>70%	
Cake production	Cake net trade	58%	<80%	34%	<70%	Balancing figure: Net trade = Production - Demand
Cake demand	Cake net trade	-42%	<80%	17%	<70%	Balancing figure: Net trade = Production - Demand
Population	Cake demand	86%	>80%	75%	>70%	
Cake demand	Yield	100%	>80%	99%	>70%	
World oil price	Oil price	97%	>80%	93%	>70%	
World palm price	Oil price	95%	>80%	90%	>70%	
World cake price	Cake price	99%	>80%	98%	>70%	
Oil price	Seed price	87%	>80%	75%	>70%	
Cake price	Seed price	85%	>80%	73%	>70%	

Some links in the causal loop diagram were not supported by the statistical analysis, as briefly explained in Table 3.1. Even though Table 3.1 illustrates that there is no correlation between the seed price and area, we know from field data that the higher the price for a commodity the more competitive the commodity is compared to other crops (provided that the costs of the crops are comparable), and the more producers will plant the crop, increasing the area under production (BFAP, 2022). The indirect reverse is also true as higher seed production will decrease the price of the seed due to supply and demand dynamics (Smith, 2010). The data does not statistically support these two links because the variables are also affected by other variables with stronger correlations. The area is not only dependent on seed price but is also affected by the historic area. Besides seed production, the seed price is also dependent on oil and cake prices. The weight for these links with poor statistical correlations was set to be lower in the mathematical formulation in Section 3.3.2 to take the lower correlation into account when calculating the variables.

The links between seed, oil and cake net trade volumes with production and demand are also not supported by the statistical analysis because net trade is a balancing figure between consumption and production, as a country imports the remaining required local volumes, and exports the excess volumes (Rosegrant et al., 2008). The gross margin for processors is calculated by subtracting the cost of seed and processing from the revenue of oil and cake (Weil et al., 2013). Because trade and the gross margin are calculated with an additive formula, no correlation can clearly be identified, as one variable can offset the impact of another variable in the statistical correlation analysis.

The links to calculate the net income for producers, processors and traders are not analysed in Table 3.1 because they are purely calculations from widely applied formulas. This includes the links to calculate utilisation, processing cost, gross margin and net income. This cannot be verified by statistical data but is clearly defined in the net income formula further discussed in Section 3.3.

Importantly, there is a strong correlation between processor net income and seed demand (86%), as well as area and seed demand (98%), supporting the final statement in the dynamic hypothesis that an increase in processor profitability will increase the seed demand, which provides seed producers with a reliable seed market, increasing the production.

3.3 Model Formulation

The relationships illustrated in the causal loop diagram were quantified with the mathematical formulas represented in the stock-flow diagram, to represent the reality of the Tanzanian sunflower industry. The stock-flow diagram represents the feedback structure of the dynamic hypothesis, while the mathematical formulation within the stock-flow diagram analytically quantifies the feedbacks and links. The mathematical formulas include parameters (original values and weights), as discussed in Section 3.3.3.

3.3.1 Stock-flow Diagram

The stock-flow diagram (depicted in Figure 3.8) was constructed from the causal loop diagram, as illustrated in Figure 3.7. The stock-flow diagram is a system of differential equations that represents the feedback structure of the dynamic hypothesis (Sterman, 2000a).

The structure of the stock-flow diagram was based on the logical flow of the Tanzanian sunflower value chain volume flow in Figure 3.3, by starting with the seed production, local seed sales and trade, and then moving into the product (oil and cake) production with their local sales and trade. In addition to the logical material flow, the prices were also added to the stock-flow diagram.

Figure 3.8 also illustrates the model developed in AnyLogic simulation software. The blocks represent stocks, the broad arrows represent flows, the thin arrows represent links for feedback loops, the circles represent dynamic variables that change over time and the circles with a triangle represent parameters that remain constant. The main channel is the flow of material from seed production to seed sales (while the seed balance can also be imported or exported), to seed processing into oil and cake, and finally to the oil and cake production and trade (sales, imports and exports). The smaller stock-flow combinations on the left, top and bottom represent the price changes, that are not physical material flows, but changes with a flow characteristic, as done by Rich and Dizyee (2016). At the bottom of Figure 3.8, the processor profitability is calculated by taking into account a weighted seed price (depending on the locally sourced and imported seed volumes processed), variable cost and fixed cost (affected by the processor utilisation). The producer gross margin is also calculated at the bottom, as well as the net income of each node. An event is triggered annually to produce seed in line with the actual Tanzanian sunflower harvest. The ”Total Net Income” variable at the top of Figure 3.8 captures the net income of all nodes for analysis purposes.

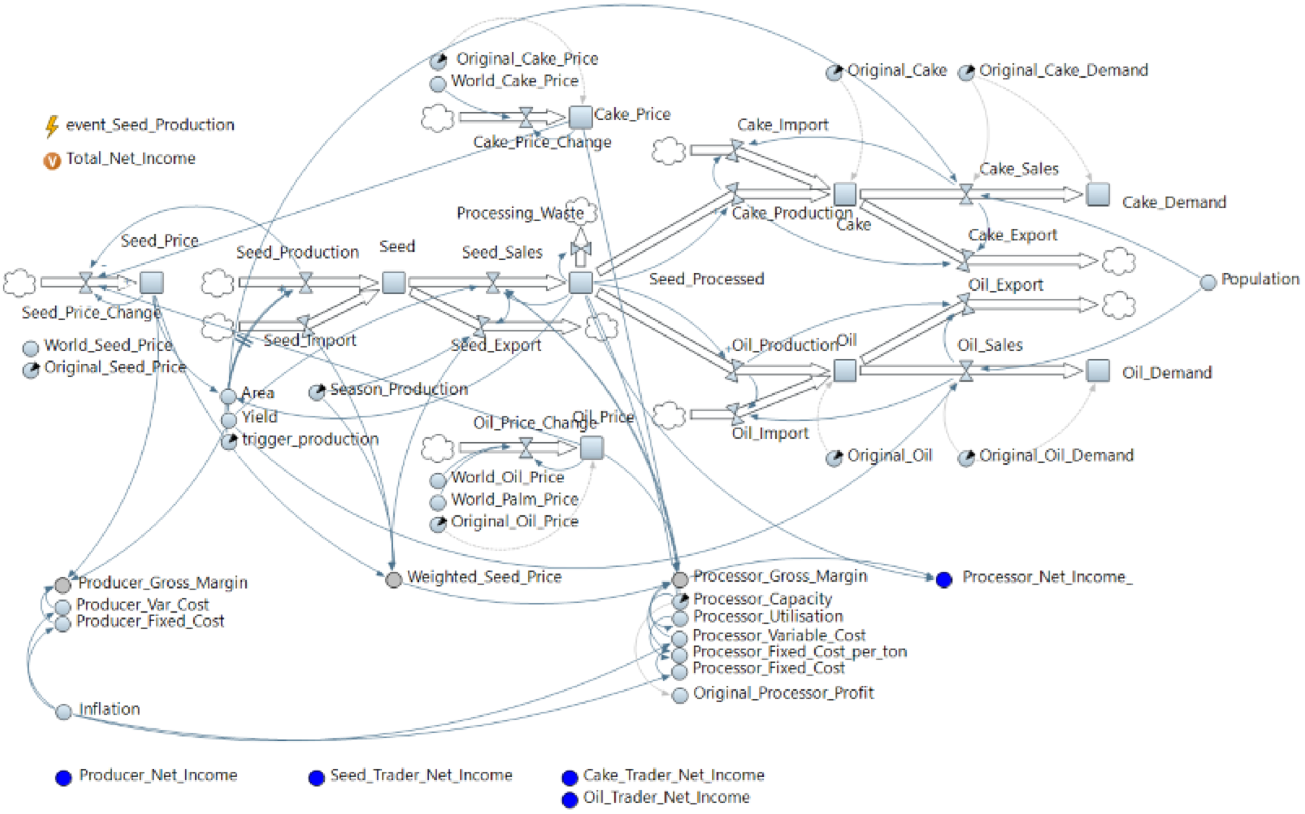

Figure 3.8: Basic Stock-flow Diagram

3.3.2 Mathematical Formulation

To develop the stock-flow diagram in Figure 3.8, mathematical formulas were developed based on the causal loop diagram in Figure 3.7, and according to causal loop data analysis in Section 3.2.2 where correlations between the different variables were determined. The correlation between variables was used as an initial weight value to specify the level of impact that one variable has on another.

The formulation step followed an iterative approach that started with the initially developed formulas based on the causal loop diagram and correlations between variables, and then running the model and comparing it to the historic data gathered and validated, as discussed in Section 3.4.1. If the model did not align with the historic production volumes, demand volumes and prices, a new iteration was executed by changing the mathematical formula, re-running the model and comparing it to the historical data. This iterative approach was executed until model validation and verification (discussed in Section 3.4) was achieved. The final formulas are discussed and represented in this section.

Stock-flow Diagram Formulation

The system dynamic model is a dynamic (non-static) model that changes over time, that needs to be modelled with time (t) in the mathematical formulations.

The first node in the Tanzanian sunflower value chain is the seed production node. Seed production (S_b) depends on the area under production (a) and the sunflower yield (y) (Rosegrant et al., 2008), and is calculated by multiplying the two variables as done in Equation 3.1.

$$S_b(t) = a(t)y(t) \tag{3.1}$$

Sunflower seed production only happens once a year when the planted area is harvested. To take the cyclic behaviour into consideration, the model incorporated a lag that delays the seed production, such that seed is produced all at the same time, once a year, over two months. This is done by including a production trigger (driven by an event), which is equal to one in the months when sunflower seed is harvested in Tanzania (July and August), and zero when no harvesting occurs. The remaining formulas in the AnyLogic model are continuous because they do not have a physical event delaying them and can occur continuously in the real-life system.

Due to continuous research and developments in food security, it is assumed that new technology and varieties will appear in the future, which will slowly increase the yield over time (OECD, 2023). Hence a new yield level is introduced each year through an input table in the model to take the yield increase into account.

Because producer profitability affects the area planted, and the price is the main driver of the producer margin (as assumed in the dynamic hypothesis (Simchi-Levi et al., 2014), area (a) is dependent on the seed price (P_s) and is thus multiplied by the current seed price and divided by the model's original seed price. Similarly, the area is also dependent on the seed demand, or seed sales (S_c) and thus multiplied by the current divided by the historic seed sales. Furthermore, producers often continue planting what they are used to planting and know how to plant. For this reason, the original area under production ($a(0)$) is multiplied by the weight that the historic area carries and added in Equation 3.2. Each component of the equation is multiplied by a weight according to how much the variables affect the area. The weight between the original area and the current area ($w_{a(0)a(t)}$), the weight between seed price and area ($w_{P_s a(t)}$) and between seed processed and area ($w_{S_c a(t)}$), were determined from the data analysis in Section 3.2.2, and adjusted as necessary to align the model with the historic data for verification.

$$a(t) = w_{P_s a(t)} a(0) \frac{P_s(t)}{P_s(0)} + w_{S_c a(t)} a(0) \frac{S_c(t)}{S_c(0)} + w_{a(0)a(t)} a(0) \tag{3.2}$$

The seed producer stock (S_{bs}) is calculated by subtracting the outflow of seed volumes locally procured (S_c) and exported (S_e) from the sum of seed locally produced (S_b) and imported (S_i), as depicted in Equation 3.3.

$$S_{bs}(t) = \frac{d(S_{bs})}{dt} = S_b(t) + S_i(t) - S_c(t) - S_e(t) \tag{3.3}$$

The seed imported is the balance between the seed locally procured (S_c) and locally produced (S_b) (Rosegrant et al., 2008). The *max* statement in Equations 3.4 is added to ensure that seed imports (S_i) can only be positive. Seed exports (S_e) are the opposite of seed imports, as seed procurement (S_c) is subtracted from seed production (S_b), and should also be larger than zero, as seen in Equation 3.5. Seed imports and exports are spread across the year, as they do not occur once a year like local seed production and processors can import seed any time of the year.

$$S_i(t) = max(S_c(t) - S_b(t), 0) \tag{3.4}$$

$$S_e(t) = max(S_b(t) - S_c(t), 0) \tag{3.5}$$

As explained in the dynamic hypothesis, the seed sales (or seed demand) depend on the historic seed processed, the profitability experienced by the seed processors and the seed production yield. The seed sales per year (S_c) are calculated by adding the previous year's seed sales ($S_c(t-1)$) multiplied by the weight of seed sales (w_{sc}), to the current year's processor profitability index (MI_c, calculated in Equation 3.7), which is multiplied by the original processor profitability ($M_c(0)$) and by the ratio of changing seed producer yield (y). The calculated seed sales are multiplied by a constant (z_1) to align the level of sales with the level observed in the historical data. Without the constant, the total sales would have been slightly lower than the actually observed historic sales.

The seed procurement per year (S_c) may not be higher than the processor capacity (v). To ensure this, a "minimum" statement was included stating that the seed sales (S_c) should be the minimum between the calculated current seed sales, or the processor capacity (v). To prevent seed from being processed if there is no available seed in the seed stock, and thus preventing the seed stock from becoming negative, a "maximum" statement is added between the minimum calculated seed sales (S_c) and zero. However, mathematically the seed sales cannot be zero, as it informs the seed processed which is further used as a denominator in calculating the best solution in the optimisation experiment. Thus the minimum value is one, which is insignificantly small to count as sales, but big enough to allow for further calculations.

$$S_c(t) = max\left(min(w_{sc} S_c(t-1) + MI_c(t) M_c(0) \frac{y(t)}{y(0)} z_1, v), 1 \right) \tag{3.6}$$

The processor profitability index considers the weighted seed price (P_{sw}), oil price (P_o) and cake price (P_c), as seen in Equation 3.7. It multiplies the product prices by their extraction rates (cake: E_c and oil: E_o), and divides it by the sum of the weighted seed price (P_{sw}), processor variable cost (C_{cv}) and processor fixed overhead costs (C_{cf}). The processor fixed overhead costs are divided by the processor utilisation (n) to model the impact of volume being processed. The variable and fixed costs are multiplied by inflation (I) from the International Monetary Fund (2023) to increase the cost over time.

$$MI_c(t) = \frac{P_o(t)E_o + P_c(t)E_c}{P_{sw}(t) + C_{cv}I + \frac{C_{cf}(t)I}{n}} \tag{3.7}$$

The weighted seed price (P_{sw}) determines the weighted average price of seed given that seed can be purchased locally at a specific price (P_s), and can be imported at a specific price (P_{si}) and that a certain amount of each is purchased depending on the system dynamics. The sum of the local seed price (P_s) multiplied by the locally produced seed (S_b) minus exports (S_e), and the imported seed price (P_{si}) multiplied by seed imports (S_i), is divided by the total locally processed seed (local production plus imports minus exports). The weighted seed price is crucial to ensure that the correct processor profitability index is used to inform seed sales (purchases by processors), as the weighted seed price takes the more expensive imported seed into account and will adjust the processor profitability index such that the model purchases less seed due to lower margins caused by the expensive imported seed.

$$P_{sw}(t) = \frac{P_s(t)(S_b(t) - S_e(t)) + P_{si}(t)S_i(t)}{S_b(t) - S_i(t) + S_e(t)} \tag{3.8}$$

The seed processed stock (S_{cs}) is calculated by a differential equation that subtracts the outflows from the inflows, namely subtracting cake (C_b), oil (O_b) and waste (W) production from seed procured (S_c). When sunflower seeds are processed, not all seeds are converted into products, and roughly 8% of waste is produced (W), which is sold at a very low cost.

$$S_{cs}(t) = \frac{d(S_{cs})}{dt} = S_c(t) - C_b(t) - O_c(t) - W(t) \tag{3.9}$$

The production of sunflower cake (C_c) and oil (O_c) is simply the stock of seed processed (S_{cs}) multiplied by their respective extraction rates (oil: E_o and cake: E_c). The remaining material of the seed stock is wasted and calculated in Equation 3.12 by subtracting the oil and cake extraction rates from one and multiplying the solution by the seed processed stock.

$$O_c(t) = S_{cs}(t)E_o \tag{3.10}$$

$$C_c(t) = S_{cs}(t)E_c \tag{3.11}$$

$$W(t) = S_{cs}(t)(1 - E_o - E_c) \tag{3.12}$$

The stock of oil (O_s) and cake (C_s) is calculated in the same way as seed stock is calculated, by subtracting the production and exports from the local production and imports.

$$O_s(t) = \frac{d(O_s)}{dt} = O_b(t) + O_i(t) - O_c(t) - O_e(t) \tag{3.13}$$

$$C_s(t) = \frac{d(C_s)}{dt} = C_b(t) + C_i(t) - C_c(t) - C_e(t) \tag{3.14}$$

The oil stock also includes imported palm oil, as local sunflower production is insufficient to meet the Tanzanian oil demand. The imported oil is thus the balance between locally produced oil (O_b) and local oil consumption or sales (O_c). Oil from other oilseeds (like canola, soybean and niger seed) is excluded in the local oil production, as Tanzania produces limited other oil (other than sunflower oil) and can be disregarded (FAOSTAT, 2022).

The *max* formula between the trade flows and zero, is used to ensure that oil and cake imports do not become negative and then represent exports and that the exports do not include import flows.

$$O_i(t) = max(O_c(t) - O_b(t), 0) \tag{3.15}$$

$$O_e(t) = max(O_b(t) - O_c(t), 0) \tag{3.16}$$

$$C_i(t) = max(C_c(t) - C_b(t), 0) \tag{3.17}$$

$$C_e(t) = max(C_b(t) - C_c(t), 0) \tag{3.18}$$

Local oil and cake sales or demand (O_c and C_c) change with the population change (Simchi-Levi et al., 2014). Hence, the original oil and cake demand is multiplied by the population (k) of the current year and divided by the original population in the starting year. The population change is entered as an input table into the model (United Nations, 2023).

From the historical data trends, it is clear that cake and oil are also dependent on yield (y), as sunflower seed is mainly consumed in the households that produce the seeds. These households will consume what they produce and not necessarily more or less (Simchi-Levi et al., 2014). However, as the population grows, more people will consume oil and cake. Thus, the population indicates the trend of the product demand (upward or downward) and the yield merely indicates the fluctuation (if less oil and cake are consumed in a year due to drought or if more is consumed because more product is available). The demands are multiplied by constants (z_2 and z_3) to align the historic data with the model.

$$O_c(t) = O_d(0)\left(\frac{k(t)}{k(0)}\right)\left(\frac{y(t)}{y(0)}\right)z_2 \tag{3.19}$$

$$C_c(t) = C_d(0)\left(\frac{k(t)}{k(0)}\right)\left(\frac{y(t)}{y(0)}\right)z_3 \tag{3.20}$$

Finally, oil demand stocks (O_{ds}) and cake demand stock (C_{ds}), as well as oil and cake trade stocks (O_{ts} and C_{ts}) are simply calculated by adding the inflows, which are only the single representable local sales (O_d and C_d) and export flows (O_e and (C_e).

$$O_{ds}(t) = \frac{d(O_{ds})}{dt} = O_c(t) \tag{3.21}$$

$$C_{ds}(t) = \frac{d(C_{ds})}{dt} = C_c(t) \tag{3.22}$$

$$O_{ts}(t) = \frac{d(O_{ts})}{dt} = O_e(t) \tag{3.23}$$

$$C_{ts}(t) = \frac{d(C_{ts})}{dt} = C_e(t) \tag{3.24}$$

The seed price (P_s) is a stock adjusted by the seed price change flow (P_{sc}) in the stock-flow diagram, as done by Rich and Dizyee (2016) and depicted in Equation 3.25. The seed price change is influenced by the dynamic oil and cake price and seed production (Smith, 2010). It is calculated by multiplying a weight (w_{P_s}) by the product prices (P_o and P_c) and by their extraction rates (E_o and E_c) and subtracting the seed production volumes (S_b) and the previous year's price ($P_s(t-1)$). The production volume is divided by 1000 and multiplied by the correlation between seed produced and seed price ($w_{s_bP_s}$), as calculated in Section 3.2.2, which can also be seen as the price elasticity of seed supply and the seed price. Similarly, the product price weight (w_{P_s}) can be seen as the elasticity between the seed price and product prices. As illustrated in the correlation analysis in Table 3.1, the price and production have a negative correlation, as an increase in seed supply decreases the seed price due to supply and demand dynamics. The previous year's seed price ($P_s(t-1)$) is subtracted to calculate the new seed price and prevent the seed price from accumulating and increasing over the time horizon.

$$P_s(t) = \frac{d(P_s)}{dt} = P_{sc}(t) \tag{3.25}$$

$$P_{sc}(t) = w_{P_s}(P_o(t)E_o + P_c(t)E_c) - \frac{w_{s_b P_s} S_b(t)}{1000} - P_s(t-1) \tag{3.26}$$

As with the seed price, the oil price (P_o) is a stock adjusted by the oil price change flow (P_{oc}). The oil price is derived by the sunflower world oil price (P_{oi}) and world palm oil price (P_{oip}) (Aleksandrova and Mel'nikova, 2016; Rosegrant et al., 2008), obtained from FAPRI (2023), with the world palm oil price carrying slightly more weight (w_{ppo}) than the world sunflower oil price (w_{po}), as palm oil is the largest produced edible oil in the world (FAOSTAT, 2022). The weights (w_{ppo} and w_{po}) can be seen as the elasticity between the calculated local price and the imported prices (P_{oi} and P_{oip}). The previous oil price ($P_o(t-1)$) is subtracted to calculate the change in price.

$$P_o(t) = \frac{d(P_{os})}{dt} = P_{oc}(t) \tag{3.27}$$

$$P_{oc}(t) = w_{po}P_{oi}(t) + w_{ppo}P_{oip}(t) - P_o(t-1) \tag{3.28}$$

Similarly, the cake price is derived from the export cake price ($P_{ce}(t)$), as most cake produced in Tanzania is exported, and multiplied by cake price weight, or elasticity (w_{P_c}), as the relationship between the two variables is not one to one.

$$P_c(t) = \frac{d(P_{cs})}{dt} = P_{cc}(t) \tag{3.29}$$

$$P_{cc}(t) = w_{P_c}P_{ce}(t) - P_c(t-1) \tag{3.30}$$

Profitability Formulation

Profitability is measured as a value chain performance and sustainability indicator (Smith and McDonald, 1998), and calculated in this project for each node of the value chain. Figure 3.9 highlights in yellow the links between the profitability indicators (net income) of the different value chain nodes and the production and sales volumes as well as prices and costs in the stock-flow diagram of Tanzania's sunflower value chain.

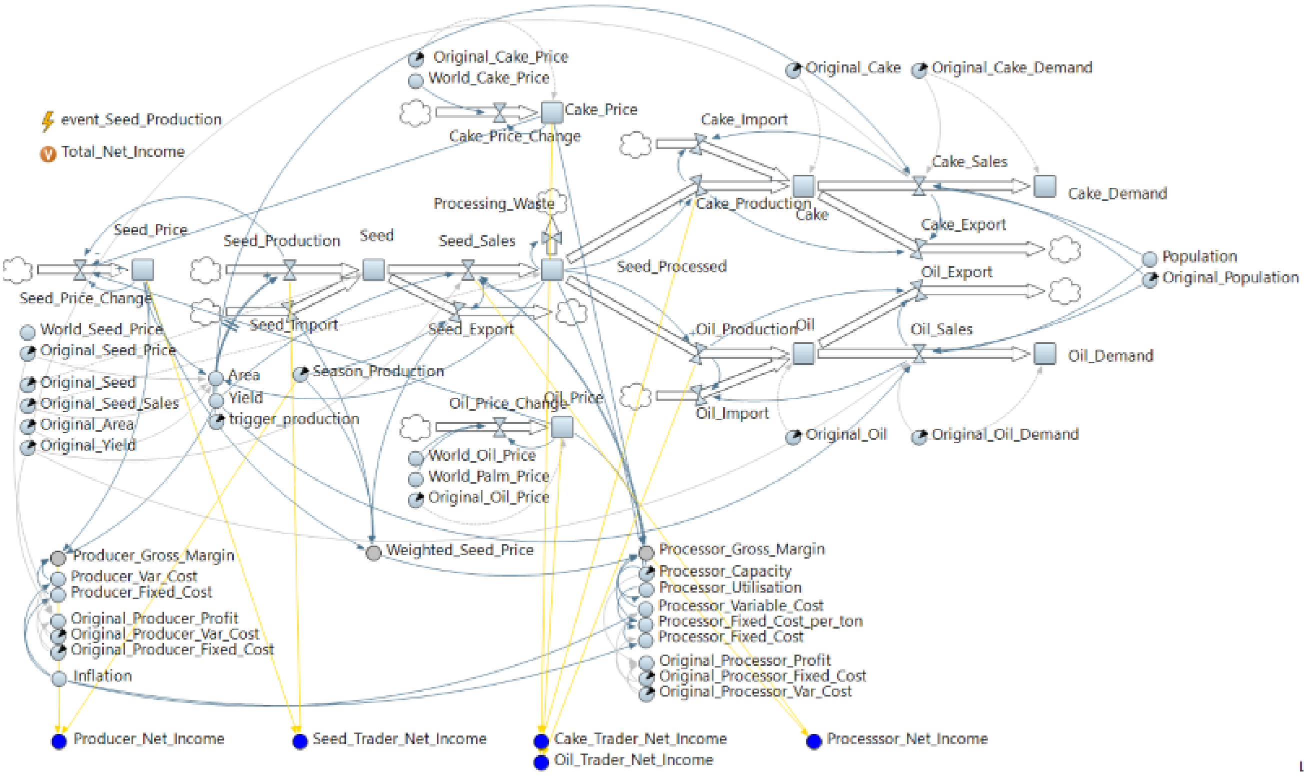

Figure 3.9: Stock-flow Diagram with Profitability Calculation

Profitability is calculated as total revenue subtracted by the total cost (including tax) (Weil et al., 2013). This can also be calculated by multiplying the gross margin per ton of product (which subtracts the total cost per ton from the revenue per ton) by the total volume sold.

The revenue that seed producers receive is the seed price (P_s) plus the by-product (Q_s) (which is multiplied by inflation (I) to increase over time). An example of a producer by-product is plant stubble after harvesting. The revenue is subtracted by the variable (C_{sv}) and fixed costs (C_{sf}) per ton of seed produced to calculate the gross margin (M_s). The variable costs are fixed per ton of seed produced, while the fixed costs are per hectare planted, and change according to how many tons are harvested per hectare. For this reason, the fixed cost is divided by the seed producer yield (y), as depicted in Equation 3.31. The producer and processor costs were adjusted with inflation over time (I) (International Monetary Fund, 2023). No income tax was deducted for producers, as sunflower is generally produced by smallholders who do not earn sufficient revenue to be liable for tax (BFAP, 2022). The net income of seed producers (NI_s) is equal to the seed producer gross margin (M_s) multiplied by the seed produced per year (S_b), given in Equation 3.32.

$$M_s(t) = P_s(t) + Q_sI(t) - C_{sv}(t)I(t) - \frac{C_{sf}(t)I}{y(t)} + Q_sI(t) \tag{3.31}$$

$$NI_s(t) = M_s(t)S_b \tag{3.32}$$

Seed traders merely sell a portion of the locally produced seed at a profit margin, depending on where they operate. Thus, their net income (N_{st}) is equal to the volume of locally produced seed (S_b), multiplied by the local seed price (P_s), and the seed trader market share (l_{st}), and finally the seed trader profit markup (r_{st}), which already takes tax into account. The same applies to the net income for oil (N_{ot}) and cake traders (N_{ct}) as illustrated in Equations 3.34 and 3.35, where O_b depicts the oil produced and C_b the cake produced, l_{ot} the oil trader market share, l_{ct} the cake trader market share, r_{ot} the oil trader profit markup and r_{ct} the cake trader profit markup.

$$NI_{st}(t) = S_b(t)P_s(t)l_{st}r_{st} \tag{3.33}$$

$$NI_{ot}(t) = O_b(t)P_o(t)l_{ot}r_{ot} \tag{3.34}$$

$$NI_{ct}(t) = C_b(t)P_s(t)l_{ct}r_{ct} \tag{3.35}$$

Sunflower processors sell oil, cake and by-products. The gross margin (M_c) calculation for a sunflower processor can be extrapolated as in Equation 3.36. The weighted seed price (P_{ws}), fixed (C_{cf}) and variable (C_{cv}) processing costs are subtracted from the oil revenue, cake revenue and byproduct revenue. The costs are multiplied by inflation (I), and the fixed cost is divided by the processor utilisation rate (n) (Afroz and Kumar Roy, 1976) as calculated in Equation 3.37 where seed processed (S_c) is divided by the processor capacity (v). The weighted seed price, as calculated in Equation 3.8, is used to ensure that if more expensive imported seed is purchased by processors, the processor gross margin decreases. The oil revenue is calculated by multiplying the price of oil (P_o) by the oil extraction rate of sunflower seed (E_o). Similarly, the cake revenue is determined by multiplying the price of cake (P_c) by the cake extraction rate of sunflower seed (E_c). The revenue of the by-product is added and calculated by multiplying the price (P_w) by the remaining extraction rate and inflation (I). Finally, the net income (NI_c) of processors is calculated by multiplying the weighted processor gross margin from Equation 3.36 by the volume of seed processed (S_c), as given in Equation 3.39.

$$M_c(t) = P_o(t)E_o + P_c(t)E_c + P_w(t)(1 - E_o - E_c)I(t) - P_{ws}(t) - C_{cv}(t)I(t) - \frac{C_{cf}(t)I(t)}{n(t)} \tag{3.36}$$

$$n(t) = \frac{S_c(t)}{v} \tag{3.37}$$

$$NI_c(t) = M_c(t)S_c(t) \tag{3.38}$$

The processor net income calculation includes an if-statement to include tax. The statement specifies that if the total net income is positive, the processor pays 20% tax (by multiplying the net income by 0.8), while if the processor's net income is negative, no tax is deducted.

The total net income of the entire value chain is calculated by summing the net income of all the nodes as done in Equation 3.39.

$$NI(t) = NI_s(t) + NI_{st}(t) + NI_{ot}(t) + NI_{ct}(t) + NI_c(t) \tag{3.39}$$

Optimisation Formulation

The optimisation model aims to determine the ideal amount of seed to be processed to maximise the total value chain net income. By determining the optimum seed sales, the optimisation experiment is conducted as done by AnyLogic (2023) in the Bass Diffusion example. The objective function maximises the total value chain net income, as in Equation 3.40, given that the seed processed (S_c) is smaller than the processing capacity (204 166 tons) but larger than zero, as defined by the constraints in Equations 3.42 and 3.43. The second optimisation experiment maximises the processor net income with Equation 3.41. The objective functions stretch across the entire time period of the Tanzanian sunflower value chain system dynamic model from 2012 to 2022 (for the historic validation model), where ($t = 0$) represents the year 2012, and where ($t = 10$) represents the year 2022.

$$Max\ Z = \sum_{t=0}^{t=10} NI(t) \tag{3.40}$$

$$Max\ Z = \sum_{t=0}^{t=10} NI_c(t) \tag{3.41}$$

Subject to:

$$S_c(t) < 204166, \forall t \in \{0, 10\} \tag{3.42}$$

$$S_c(t) > 0, \forall t \in \{0, 10\} \tag{3.43}$$

To capture the maximum net income over time, a variable was created in the base system dynamic model, which adds the net income every month over the entire time period through executing an event. In the optimisation experiment, all parameters are kept constant except the one under question, namely the seed sales to processors (S_c). The constraints of the optimisation model ensure that the seed sales do not exceed the Tanzanian sunflower processing capacity (Equations 3.42 and 3.43).

The ideal amount of seed to be processed was found by replicating 100 random runs of 500 iterations. Thus, 50,000 iterations were conducted, which ensured that the ideal seed sales would be found to maximise value chain net income. Each run of 500 iterations started with a random seed and then chose values for the seed sales to calculate the total value chain net income. If the net income of the randomly chosen seed sales value was higher than the previous iteration, it was saved, otherwise, it was discarded. This was conducted 500 times for each of the 100 runs.

The solution found by the optimisation model can be seen as the best possible amount of seed to be purchased by processors to maximise the total value chain net income given the current state of the value chain and its nodes. The solution is validated as discussed in Section 3.4.3 and 3.4.4, but optimality could not be proven given the complex dynamics of the system. However, the solution can be assumed to be ideal as a reasonable sample size (20% of the 204,166 sample points) was used to find the ideal solution.

As in the AnyLogic (2023) bass diffusion example, once the ideal solution had been found, the solution was inserted into the base model, to model and capture the system's reaction over time.

3.3.3 Parameter Estimation

The parameters in the stock-flow formulation discussed in the previous section, need to be estimated to represent the actual situation. Parameter estimation can be done from data or from making assumptions (Bala et al., 2017). This project used data, as also done by Rich and Dizyee (2016), because data is more quantifiable and a better basis to start from.

Figure 3.10 illustrates the same stock-flow diagram as in Figure 3.8, but additionally includes the parameters (illustrated as circles with a small triangle) that cannot change dynamically over time like variables. The parameters, their mathematical notation, unit, 2012 value and data source are listed in Table 3.2. The parameters were set equal to 2012 to conduct the model validation and verification. The list of required parameters was developed from the causal loop diagram in Section 3.2.2. The weight variables in Table 3.2 (not reflected on the stock-flow diagram in Figure 3.10, but in the mathematical formulas in Section 3.3.2) were determined with the data analysis in Section 3.4.1, but adjusted during model development to ensure that the model aligned with historic data. The yield, population, inflation, world sunflower seed price, world sunflower oil price, world palm oil price and world sunflower cake price change periodically every year according to input data from data sources, while the remaining parameters remain fixed as illustrated in Table 3.2.

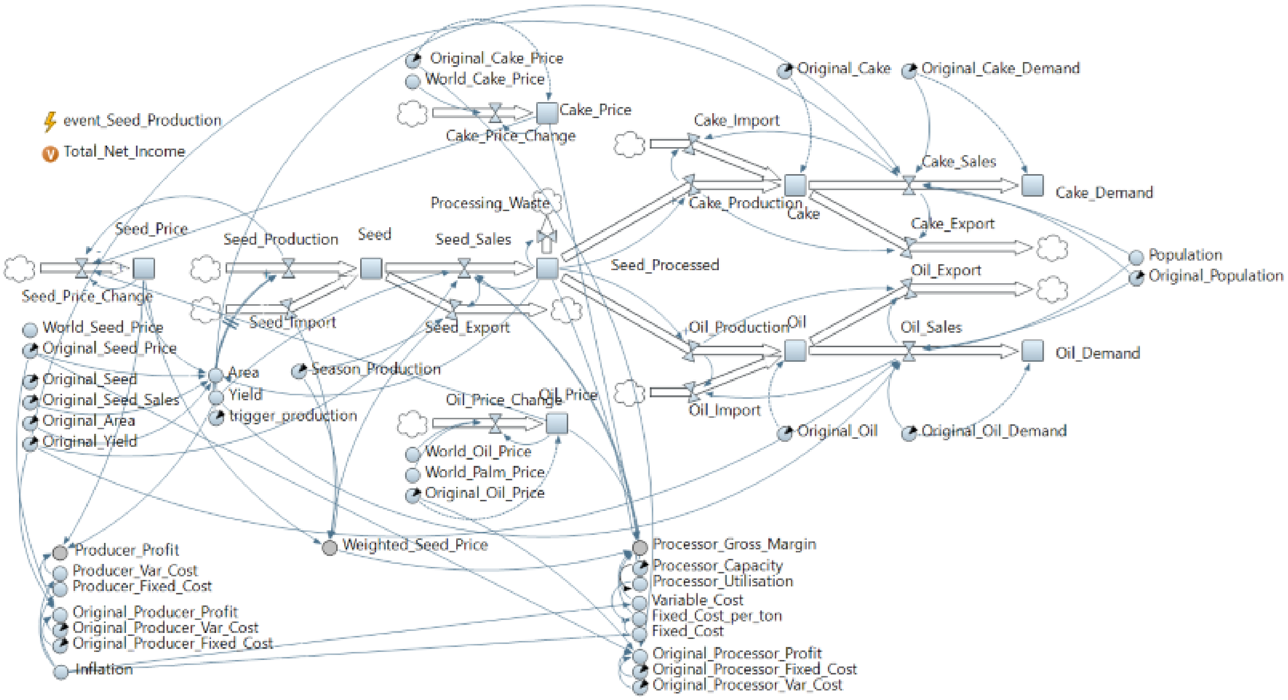

Figure 3.10: Stock-flow Diagram with Parameters

Table 3.2: Parameter Estimation

Parameter on AnyLogic Stock-flow Diagram	**Parameter in Mathematical Formulation**	**Unit**	**2012 Value**	**Data Source**	**Changing Input Variable Source**
Original Seed Produced	S_b	tons	578,039	(Tanzania Ministry of Agriculture, 2022)	
Original Production Area	a	hectare	772,354	(Tanzania Ministry of Agriculture, 2022)	
Yield	y	ton/ha	0.75	(Tanzania Ministry of Agriculture, 2022)	(OECD, 2023)
Original Seed Sales	S_c	tons	465,494	In-field data gathering by BFAP (2022)	
Original Oil Produced	O_b	tons	132,221	In-field data gathering by BFAP (2022)	
Original Cake Produced	C_b	tons	366,221	In-field data gathering by BFAP (2022)	
Oil Extraction Rate	E_o	%	28	In-field data gathering by BFAP (2022)	
Cake Extraction Rate	E_c	%	64	In-field data gathering by BFAP (2022)	
Original Oil Demand	O_c	tons	319,130	In-field data gathering by BFAP (2022)	
Original Cake Demand	C_c	tons	394,110	In-field data gathering by BFAP (2022)	
Original Seed Price	P_s	USD/ton	270	(Tanzania Ministry of Agriculture, 2022)	
Original Oil Price	P_o	USD/ton	1,405	(Tanzania Ministry of Agriculture, 2022)	
Original Cake Price	P_c	USD/ton	159	In-field data gathering by BFAP (2022)	
World Seed Price	P_{si}	USD/ton	806	(FAPRI, 2023)	(FAPRI, 2023)
World Oil Price	P_{oi}	USD/ton	1,626	(FAPRI, 2023)	(FAPRI, 2023)
World Palm Oil Price	P_{oip}	USD/ton	1,139	(FAPRI, 2023)	(FAPRI, 2023)
World Cake Price	P_{ci}	USD/ton	175	(FAPRI, 2023)	(FAPRI, 2023)
Original Producer Variable Cost	C_{sv}	USD/ton	94	In-field data gathering by BFAP (2022)	
Original Producer Fixed Cost	C_{sf}	USD/ton	31	In-field data gathering by BFAP (2022)	
Original By-product Price of Producers	Q_s	USD/ton	157	In-field data gathering by BFAP (2022)	
Original Processor Variable Cost	C_{cv}	USD/ton	56	In-field data gathering by BFAP (2022)	
Original Processor Fixed Cost	C_{cf}	USD/ton	38	In-field data gathering by BFAP (2022)	
Original By-product Price of Processors	P_w	USD/ton	157	In-field data gathering by BFAP (2022)	
Population	k	people	44,929,000	(United Nations, 2023)	(United Nations, 2023)
Crusher Capacity	v	tons	2,450,0000	In-field data gathering by BFAP (2022)	
Weight: Historic Area to Area	$w_{a(0)a(t)}$	%	37.8	Data correlation analysis Section 3.2.2	
Weight: Seed Price to Area	$w_{P_{s(t)}a(t)}$	%	50	Data correlation analysis Section 3.2.2	
Weight: Seed Processed to Area	$w_{s_c a(t)}$	%	39.7	Data correlation analysis Section 3.2.2	
Weight: Seed Producion to Seed Price	$w_{s_b P_s}$	%	-20	Data correlation analysis Section 3.2.2	
Weight: Product Price	w_{P_s}	%	75	Data correlation analysis Section 3.2.2	
Weight: World Oil Price to Oil Price	w_{po}	%	51.4	Data correlation analysis Section 3.2.2	
Weight: Palm Oil Price to Oil Price	w_{ppo}	%	62.5	Data correlation analysis Section 3.2.2	
Weight: World Cake Price to Cake Price	w_{P_c}	%	100	Data correlation analysis Section 3.2.2	
Market Share: Seed Trader	l_{st}	%	20	Data correlation analysis Section 3.2.2	
Profit Markup: Seed Trader	r_{st}	%	12	Data correlation analysis Section 3.2.2	
Market Share: Oil Trader	l_{ot}	%	3	Data correlation analysis Section 3.2.2	
Profit Markup: Oil Trader	r_{ot}	%	9	Data correlation analysis Section 3.2.2	
Market Share: Cake Trader	l_{ct}	%	20	Data correlation analysis Section 3.2.2	
Profit Markup: Cake Trader	r_{ot}	%	16	Data correlation analysis Section 3.2.2	
Constant: 1	z_1		1.3	Data correlation analysis Section 3.2.2	
Constant: 2	z_2		1.2	Data correlation analysis Section 3.2.2	
Constant: 3	z_3		1.1	Data correlation analysis Section 3.2.2	
Inflation	I		100	(International Monetary Fund, 2023)	(International Monetary Fund, 2023)

3.4 Model Verification and Validation

Model validation is very important to establish model confidence, by verifying structure, behaviour and policy implications, and ensuring real representation (Bala et al., 2017). The boundary adequacy test, dimensional consistency, historic behaviour reproductivity test, structural behaviour, logical behaviour and extreme condition tests were executed, based on literature (Bastan et al., 2016; Pejić-Bach and Čerić, 2007; Sterman, 2000a, 1992). According to Sterman (1992), these are the most widely used tests, with the behaviour reproductivity test being the most important verification and validation test as it illustrates the model's ability to replicate the past.

Data and parameter verification is done in Section 3.4.1 to ensure that the data feeding into the model and the data to which the model is compared to is correct, as a model is only as good as its data.

The model boundary adequacy test ensured that all key elements were included in the model. It was conducted after developing the causal loop diagram and ensuring that no variables were excluded and that all variables were correctly represented as endogenous or exogenous variables. Section 3.2.2 briefly discussed some variables, like weather and the Tanzanian economy, that could have an impact on the Tanzanian sunflower value chain but are not affected by the Tanzanian sunflower value chain. Furthermore, they do not impact the model's purpose of determining the impact of limited seed, and there is no clear reason for a link between the problem of limited available seed and the discussed variables. Thus, they are exogenous variables, not impacted within the model, and consequently excluded (Qudrat-Ullah, 2005).

The model's dimensional consistency was tested with a built-in function in the AnyLogic modelling software and ensured that the units were coherent and added up on either side of the equations in the model, as suggested by Pejić-Bach and Čerić (2007). By building the model according to a general value chain structure and according to the Tanzanian sunflower value chain developed in Section 3.1.1, the model's structure was ensured to represent the real-life Tanzanian sunflower value chain structure (Qudrat-Ullah, 2005). The final model was compared to the original Tanzanian sunflower value chain in Figure 3.3 and the causal loop diagram of Figure 3.7 to ensure that the final model represented the correct structure.

The historic behaviour reproductivity test ensured that the model accurately represented reality and ultimately tested the model's structure and behaviour, which compared the model results to historic data and defined the model's accuracy by calculating the percentage error (Bala et al., 2017). The model's parameters were set to 2012 values to allow projection of the historic timeline from 2012 to 2022. The model aligned on average 96% to the historic data across all indicators as illustrated in Section 3.4.2.

The structural behaviour test ensured consistency of the model structure with the real-life components, variables and parameters. The test checked that the model ran logically and reflected reality while building the model, as done by Sterman (2000a). This was done by ensuring that all variables, stocks and flows reflected values in the correct order quantity compared to historic data. The net income per value chain node was calculated separately and compared to the net income calculated by the model in Section 3.4.3.

The logical behaviour test was done in combination with the structural behaviour test and ensured that the model reflected the correct logical cyclic behaviour per month as seen in the Tanzanian sunflower industry and is further discussed in Section 3.4.3.

The extreme condition test further verified the model to check if the model responded in extreme situations as expected by the Tanzanian sunflower value chain in Section 3.4.4, and assessing if key parameters generate realistic outputs.

3.4.1 Data Source and Validation

The data used in this project was gathered during a project executed by the BFAP (2022) (for which ethical clearance was obtained) and went through extensive validation. As much data as possible was gathered for all required variables and parameters going back in history as far as possible. The data was used to develop a time series where outliers could be identified or explained. However, a time series for costs was difficult to gather and was adjusted with inflation to create a trend over time.

The first round of data was gathered from open sources and in-field data gathering, as listed in the "Original Source" column in Table 3.3. This data was gathered by experts in Tanzania through desktop studies and interviews. The original price data came from in-field interviews (BFAP, 2022) and the Tanzania Ministry of Agriculture (2022), which provides historic statistics about key agricultural products. Costs and processing capacity were obtained from in-field interviews (BFAP, 2022). Seed production volumes (with area and yield) were obtained from the Tanzania Ministry of Agriculture (2022), while oil and cake production, sales, and local trade volumes were gathered through in-field data gathering by BFAP (2022) as the Tanzanian Ministry of Agriculture does not capture this information. The import and export volumes were gathered from ITC Trade Map (2022).

Table 3.3: Tanzania Sunflower Value Chain Data Sources

Data		**Original Source**	**Validation Source**
Prices	Seed	(Tanzania Ministry of Agriculture, 2022)	In-field data gathering by BFAP (2022)
			(Oil World, 2022)
			(ITC Trade Map, 2022) unit values (values traded divided by volumes traded)
			Literature: (Mushi, 2016)
	Oil	(Tanzania Ministry of Agriculture, 2022)	In-field data gathering by BFAP (2022)
			(Oil World, 2022)
			(ITC Trade Map, 2022) unit values (values traded divided by volumes traded)
			Literature: (Mushi, 2016; Rordorf Karl-Marx-Str, 2011)
	Cake	In-field data gathering by BFAP (2022)	(ITC Trade Map, 2022) unit values (values traded divided by volumes traded)
			Literature: (Mushi, 2016; Rordorf Karl-Marx-Str, 2011)
Costs	Seed production cost	In-field data gathering by BFAP (2022)	(Agri benchmark, 2022) (international crop production benchmark)
			BFAP expertise of South Africa
			Literature: (Dalberg, 2019; Mushi, 2016; Rordorf Karl-Marx-Str, 2011)
	Processing cost	In-field data gathering by BFAP (2022)	BFAP expertise of South Africa
			Literature: (FAOSTAT, 2022; Mushi, 2016)
	Oil trader markup	In-field data gathering by BFAP (2022)	Literature: (Dalberg, 2019)
	Cake trader markup	In-field data gathering by BFAP (2022)	Literature: (Dalberg, 2019)
Volumes	Local Seed production	(Tanzania Ministry of Agriculture, 2022)	(FAOSTAT, 2022)
			Literature: (Rordorf Karl-Marx-Str, 2011)
	Seed imports	(ITC Trade Map, 2022)	Mirror data of (ITC Trade Map, 2022)
	Seed exports	(ITC Trade Map, 2022)	Mirror data of (ITC Trade Map, 2022)
	Seed processed	In-field data gathering by BFAP (2022)	(FAOSTAT, 2022)
	Seed traded	In-field data gathering by BFAP (2022)	Literature: (Dalberg, 2019)
	Oil production	In-field data gathering by BFAP (2022)	(FAOSTAT, 2022)
	Oil imported	(ITC Trade Map, 2022)	Mirror data of (ITC Trade Map, 2022)
	Oil exported	(ITC Trade Map, 2022)	Mirror data of (ITC Trade Map, 2022)
	Oil sales	In-field data gathering by BFAP (2022)	Balancing number of production and trade data
	Oil traded	In-field data gathering by BFAP (2022)	Literature: (Dalberg, 2019)
	Cake production	In-field data gathering by BFAP (2022)	(FAOSTAT, 2022)
	Cake imported	(ITC Trade Map, 2022)	Mirror data of (ITC Trade Map, 2022)
	Cake exported	(ITC Trade Map, 2022)	Mirror data of (ITC Trade Map, 2022)
	Cake sales	In-field data gathering by BFAP (2022)	Balancing number of production and export data
	Cake traded	In-field data gathering by BFAP (2022)	Literature: (Dalberg, 2019)
Yields		(Tanzania Ministry of Agriculture, 2022)	(FAOSTAT, 2022)
			Literature: (Rordorf Karl-Marx-Str, 2011)
Area		(Tanzania Ministry of Agriculture, 2022)	(FAOSTAT, 2022)
			Literature: (Rordorf Karl-Marx-Str, 2011)
Processing capacity		In-field data gathering by BFAP (2022)	Literature: (Dalberg, 2019)

Then the data was analysed, dissected, and validated by analysts at the BFAP with sources listed in the "Validation Source" column in Table 3.3. This entailed comparing the local prices to world prices from Oil World (2022), and other literature studies and calculating the unit value (dividing trade value by trade volume) from ITC Trade Map (2022). The costs were compared to literature and the costs realised in other countries, while specifically comparing cost items included to ensure that no costs were omitted. If only outdated cost data was available (not specific for 2012 or 2022), the costs were adjusted with inflation to be able to compare the costs with the data gathered in Tanzania. Production volumes, area and yield were compared to volumes reported by the FAOSTAT (2022), and other literature. Import and export volumes of seed, oil and cake were validated by comparing the original source data to other countries' mirror data (other countries' import and export reports compared to what Tanzania reported on ITC Trade Map (2022)). Oil and cake sales volumes were compared to the balancing figure of local production and trade. Lastly, processing capacity was compared to another study conducted by Dalberg (2019) on Tanzania's sunflower industry.

Overall, the original and validated source data compared relatively well. There were some differences, which were resolved with the "reality test" of determining if the gathered data was practically feasible to realise under the specific conditions in Tanzania. One big error realised was the sunflower yield, where the reality test indicated that the recorded yield was quite high and difficult to obtain under the specific climatic, ecological and seed variety conditions. This meant that the volumes produced were also incorrect (BFAP, 2022). Any abnormalities, uncertainties or unexpected values were discussed with the Tanzanian in-country experts, who then went back into the field to gather more data or discuss the data with stakeholders. This process was repeated up to five times depending on the data parameter, until industry stakeholders agreed that the data represented the industry accurately.

3.4.2 Historic Behaviour Reproductivity Validation

The model's key output data, and data required to calculate the net income per node, namely the sunflower seed, oil and cake prices, as well as production volumes and sales were compared to the actual historic data. The historical data was only available annually, hence the model could not be compared on a monthly basis (for which the model run time was set to take harvest cycles into account). Table 3.4 lists the variables with the statistical correlation and coefficient of determination, highlighting if the variation is statistically acceptable or not (if the correlation is above 80% and the R-square value is above 70% (Frost, 2019)).

Figure 3.11 illustrates the historic data, modelled data and the percentage error (right axes) over the modelled time period from 2012 to 2022 for price, supply and demand data. The model's trends do not align 100% with the historical data, as unquantifiable exogenous factors (like weather, political unrest and more) affect the system and cannot be modelled, and fall outside of the system boundary. However, the correlation between the modelled and actual historic data of all variables is statistically significant, except for the cake price, as illustrated in Table 3.4.

Table 3.4: Historic Behaviour Reproductivity Statistical Analysis Summary from 2012 to 2022

Variable	**Correlation**		**R-square**	
Seed Price (US$/ton)	84%	>80%	70%	>70%
Seed Production (tons)	94%	>80%	88%	>70%
Seed Sales (tons)	85%	>80%	72%	>70%
Oil Production (tons)	91%	>80%	83%	>70%
Oil Sales (tons)	92%	>80%	84%	>70%
Oil Price (US$/ton)	91%	>80%	82%	>70%
Cake Production (tons)	92%	>80%	85%	>70%
Cake Sales (tons)	90%	>80%	80%	>70%
Cake Price (US$/ton)	34%	<80%	12%	<70%

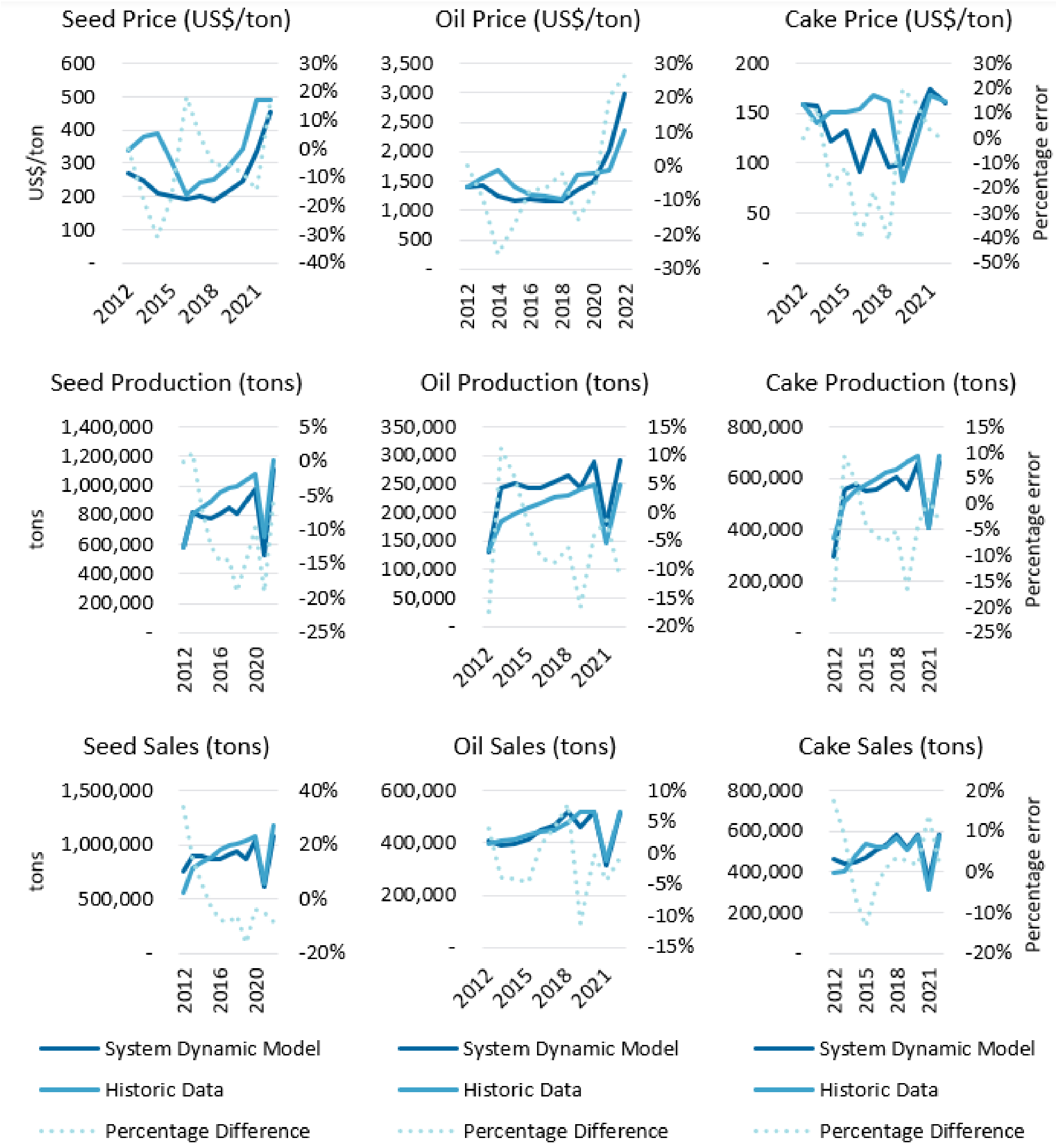

Figure 3.11: Historic Price, Production and Demand Data and Model Comparison

The statistical significance between the modelled and actual historic cake price data is very low (correlation: 34% and R-square: 12%). This begs the question if the impact of another variable was omitted when modelling the Tanzanian sunflower value chain and cake price. Table 3.5 looks at the correlations of the sunflower cake price with all other variables in the system boundary, to check if any other variable has a significant correlation level (above 80%).

Table 3.5: Correlation Between the Sunflower Cake Price and All Other Variables

Sunflower Value Chain System Variables	**Correlation**	
Sunflower Area Harvested	13%	<80%
Historic Area	17%	<80%
Sunflower Yield	7%	<80%
Sunflower Production	11%	<80%
Sunflower Imports	27%	<80%
Sunflower Total Domestic Consumption	10%	<80%
Sunflower Crush for Market (SME & Commercial)	12%	<80%
Sunflower Cake Production	9%	<80%
Sunflower Cake Net Exports	-32%	<80%
Sunflower Cake Domestic Consumption	20%	<80%
Sunflower Oil Production	9%	<80%
Sunflower Oil Net Exports	21%	<80%
Sunflower Oil Domestic Consumption	7%	<80%
Sunflower Price: Farm Gate	-20%	<80%
Sunflower Oil Price	-47%	<80%
Sunflower Cake Price	100%	>80%
Sunflower Oil - Import Parity	-37%	<80%
Palm Oil - Import Parity Price	-66%	<80%
Sunflower Cake - Export Parity	9%	<80%
Producer Gross margin	-17%	<80%
Processor Gross Margin	21%	<80%
Processor Net Income	21%	<80%
Population	-9%	<80%

Table 3.5 illustrates that the correlations between all variables and the cake price are below 50%, thus all variables in the model have a statistically insignificant impact on the cake price. Thus, the model has been treated according to literature specifications for South African sunflower cake prices, namely that the cake price depends on the Argentine import parity cake price (Boshoff, 2008), as no literature for the Tanzanian sunflower cake price could be found.

A further study is proposed to determine the factors that affect the sunflower cake price in Tanzania. The low accuracy of the model can partly be contributed to the cake price's dependency on other exogenous factors that have been excluded in this study, like the feed and livestock industry. Given that these factors are not the focus of the study (namely to illustrate the impact of limited seed availability), including them would not benefit this study. The cake price, even though it is not perfectly accurate, is accurate enough, as the price increases and decreases with a change in supply and demand, but further research is proposed to determine what variables have an effect on the cake price.

3.4.3 Logical Structural and Behaviour Validation

This section illustrates the dynamics of the system in a monthly view to validate the seasonal behaviour of the sunflower industry of the model. Firstly, the production and sales volumes, as well as the prices are discussed and validated, and then the net income per node is validated by using the validated volumes and prices. Finally, the behaviour of the optimisation model is discussed.

Volume and Price Behaviour Validation

Figure 3.12 illustrates the volume of seed produced per month and the volumes of seed purchased by processors each month over ten years, as well as the seed price. The figure illustrates how the seed price decreases with an increase in seed production, and how the processors jump to the opportunity and purchase more seed at lower prices, to be stored until processing. This is exactly what is expected to happen according to microeconomic supply and demand dynamics (Smith, 2010).

The increase in seed price trends over the last two years was firstly due to the increase in oil prices attributed to the Covid-19 pandemic (Elleby et al., 2020) and the Russia-Ukraine war (Liadze et al., 2022). Furthermore, Tanzania experienced a drought in 2021 (modelled through a lower yield in the input table), resulting in a significant drop in sunflower seed production as illustrated in Figure 3.12 (BFAP, 2022). These three factors resulted in a low supply of sunflower seed globally and locally, putting seed sales under pressure and increasing the price.

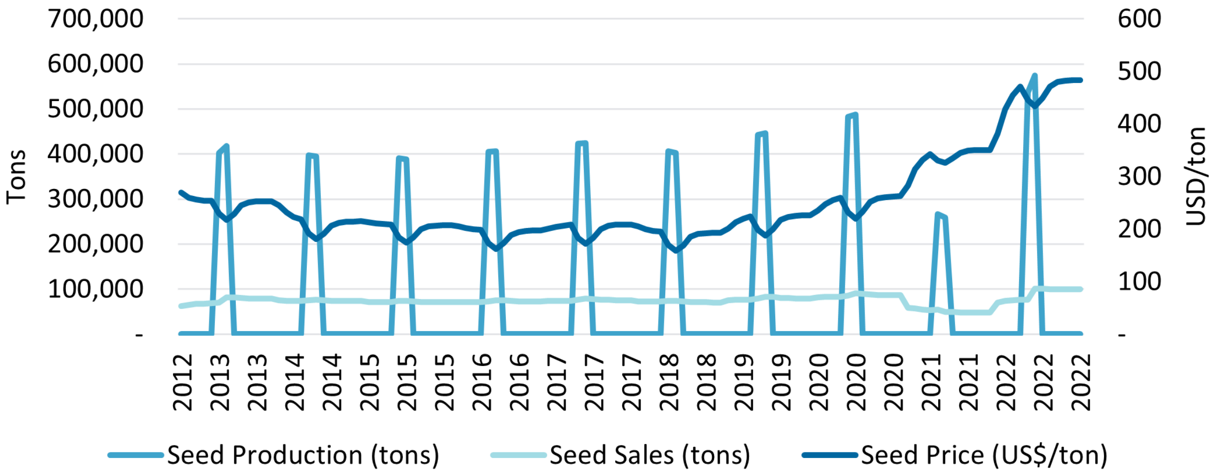

Figure 3.12: Modelled Historic Seed Production, Sales and Price

Figure 3.13 illustrates how the oil production and sales follow a similar trend to the seed sales volumes, increasing and decreasing in the same years (for example dropping from 2020 to 2022), as the local oil production is mainly made from local sunflower seed. While the volumes sold increased slowly throughout the year with a sudden jump at the beginning of the new year due to the population increase that was imposed as an input variable in the model. The oil price follows a seemingly random trend, as it is mostly dependent on international sunflower and palm oil prices.

Cake has a similar phenomenon to oil, as illustrated in Figure 3.14 but with larger production waves due to cake's higher extraction rate when producing more cake from the sunflower seed. The drastic drop in oil and cake sales in 2021 is due to a decrease in seed availability with a drop in yield due to a drought. Oil and cake demand depends on seed production because most of the oil and cake consumption is home consumption, where seed producers process and consume what they produce themselves as subsistence farmers in developing countries (Fan et al., 2013).

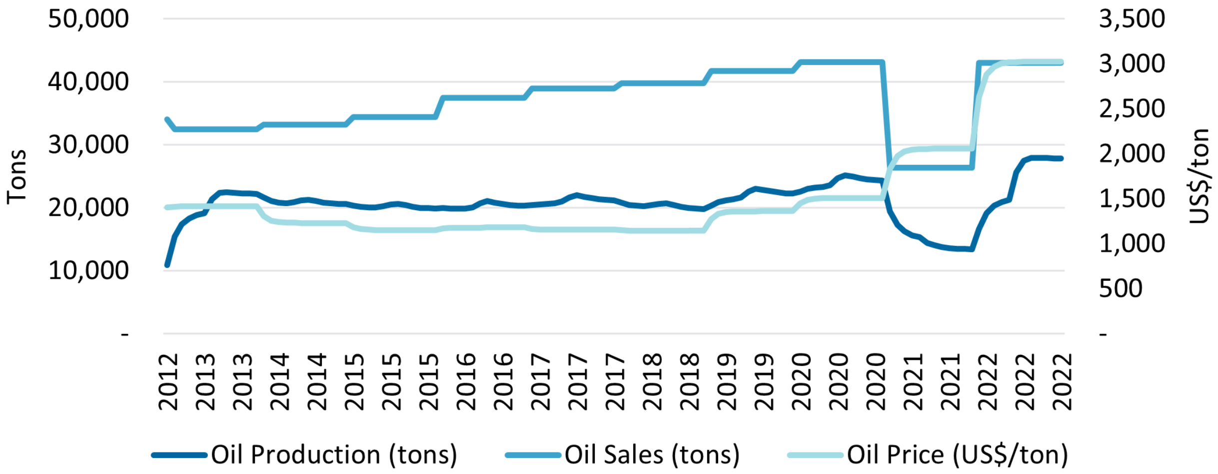

Figure 3.13: Modelled Historic Oil Production, Sales and Price

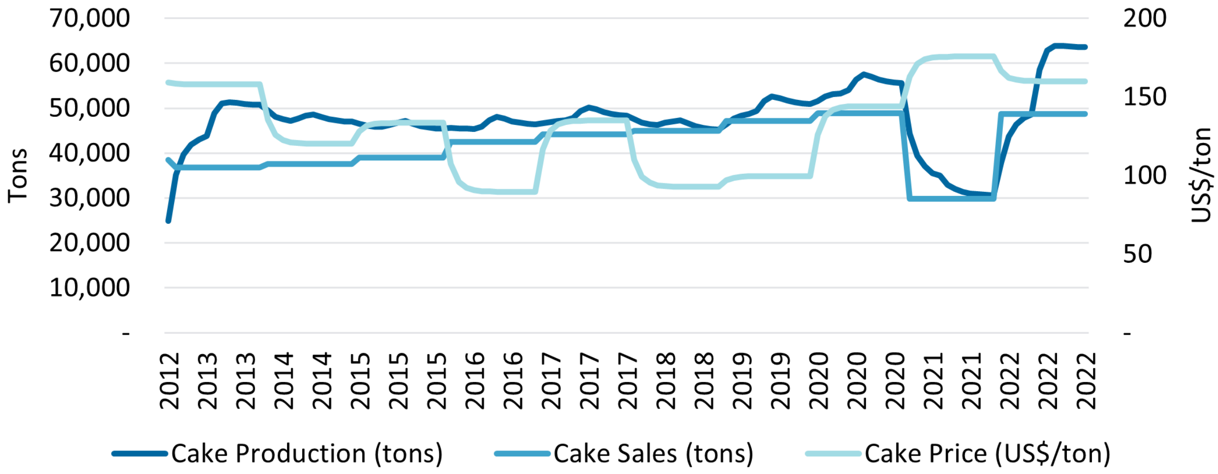

Figure 3.14: Modelled Historic Cake Production, Sales and Price

Figure 3.15 illustrates the modelled prices. As observed in the real-life oil sector, the cake price is slightly lower than the seed price. The seed and oil prices move together in the same upward trend. The seed price has a high variability due to the harvest seasonality, while the oil price is more dependent on the international oil price, and is produced throughout the year. The oil price variability is not modelled as it depends on external uncontrollable factors impossible to predict. Because cake started as a by-product of oil and due to the fact that the cake market is unestablished in Tanzania with few off-takers procuring cake, the cake price is not as volatile and does not have monthly seasonality (BFAP, 2022).

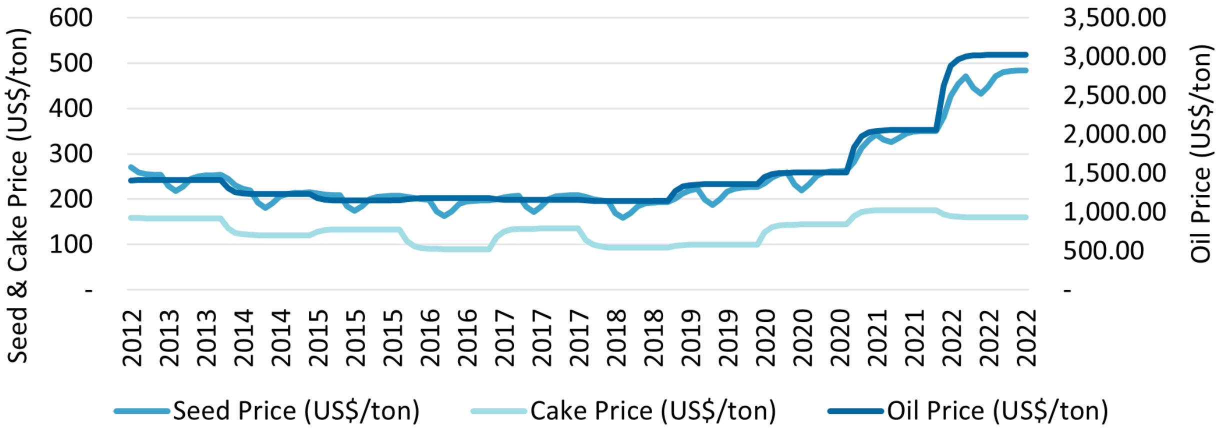

Figure 3.15: Modelled Historic Seed, Cake and Oil Prices

Figure 3.16 illustrates the normal sunflower seed price fluctuation in a year due to seasonality regarding harvesting (when the seed supply is high) and the rest of the year (where seed stocks run low). No data source for monthly Tanzanian sunflower prices could be obtained, hence world sunflower seasonality price trends were used. This is applicable, as the local price is dependent on the world price, due to Tanzania not supplying sufficient sunflower seed for the local demand, and having to import seed. The price decreases in the month of harvest (July to September) when the seed volumes enter the market, and then starts to increase again as the stock volumes decrease. Figure 3.16 illustrates that the model followed the same trend, with the price decreasing from July to September and then increasing again from September onwards, supporting the validity of the model's price output. The model's results for 2014, 2015 and 2016 are represented and show that the trend appears each year (the same applies for 2017 to 2022, however, the years were just not illustrated to avoid cluttering the figure) just at different levels depending on the sunflower harvest volumes and world sunflower seed price.

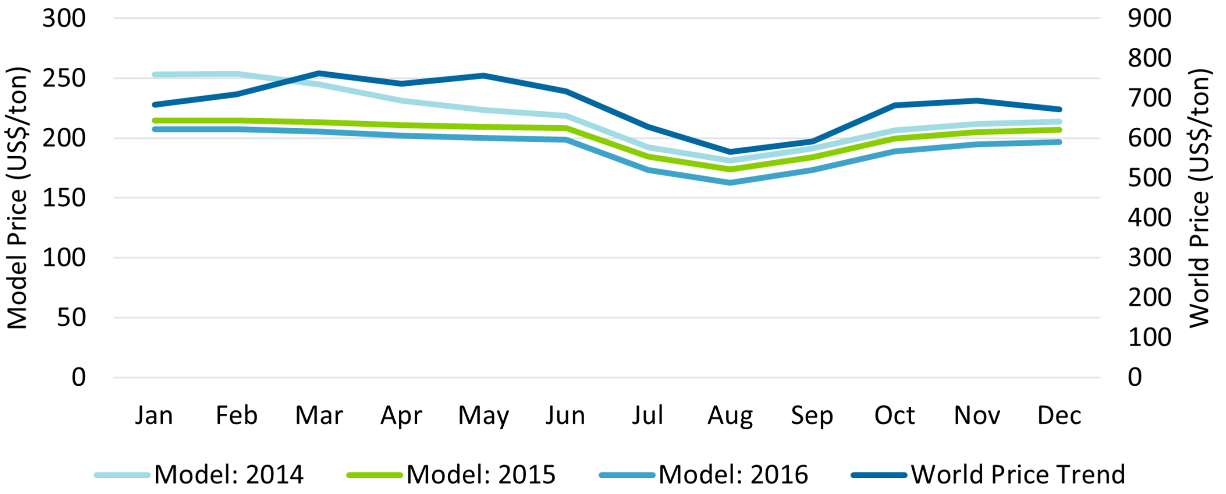

Figure 3.16: Tanzanian Sunflower Seed Seasonality Trend Compared to World Sunflower Seed Seasonality Trends

Source: (BFAP, 2022; SAGIS, 2023)

Net Income Per Node Behaviour Validation

The net income per node is used to compare the scenario results. To ensure that the model returns the financial sustainability indicator accurately, the net income per node was calculated by using the gathered price, volume and cost data (which is compared to the model generated data in Section 3.4.3) and calculating the net income separately, and then comparing the calculated results to the net income outputs of the model. Figures 3.17 to 3.21 compare these results. The model net income (named "System Dynamic Model" in the figures) and separately calculated net incomes (named "Historic Data" in the figures) do not align perfectly because the system dynamic model data calculates a weighted average net income that takes into consideration the cyclic behaviour of sunflower seed harvest volumes and prices. While the separately calculated historic data merely calculates an average net income with an average price across the year and does not take the cyclic harvest behaviour into account.

The producer node's modelled net income (depicted in Figure 3.17) is between 2013 and 2015 above the historic data net income, after which the modelled net income remains higher. However, the correlation and R-square values remain above the significance threshold at 84% (above 80%) and 71% (above 70%), indicating statistical accuracy.

The modelled processing node's net income (Figure 3.19) remains below the historic data net income but follows the same trend and the correlation and R-square values are also statistically significant (correlation: 85% and R-square: 72%). Towards the end of the modelled period, the two data sets are also closer.

The net incomes of the seed (Figure 3.18) and oil trader (Figure 3.20) nodes align very well between the model's net income and the separately calculated "Historic Data" net income. The cake trader's net income (Figure 3.21) has the poorest alignment, because of the price differences discussed in Section 3.4.3.

During the last four years, all nodes' net incomes align well between the modelled "System Dynamic Model" and the separately calculated "Historic Data" net incomes. This is due to the fact that more recent years are easier to represent as data is more easily available to explain occurrences.

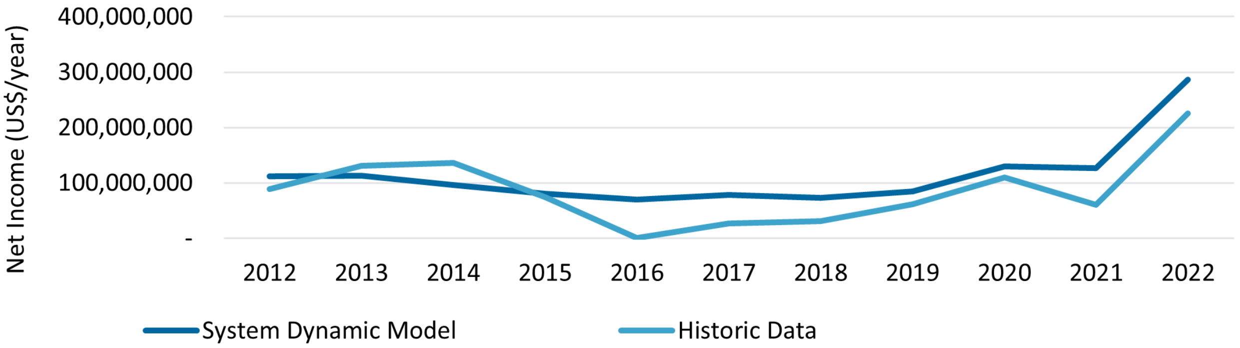

Figure 3.17: Producer Net Income Historic Comparison

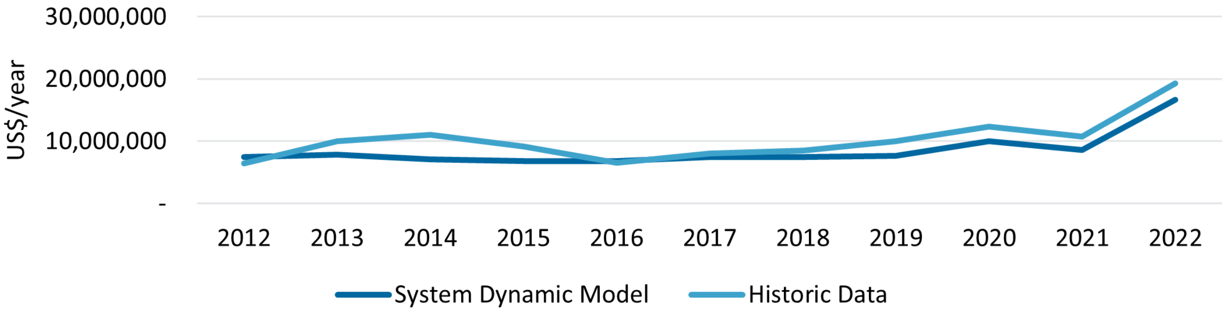

Figure 3.18: Seed Trader Net Income Historic Comparison

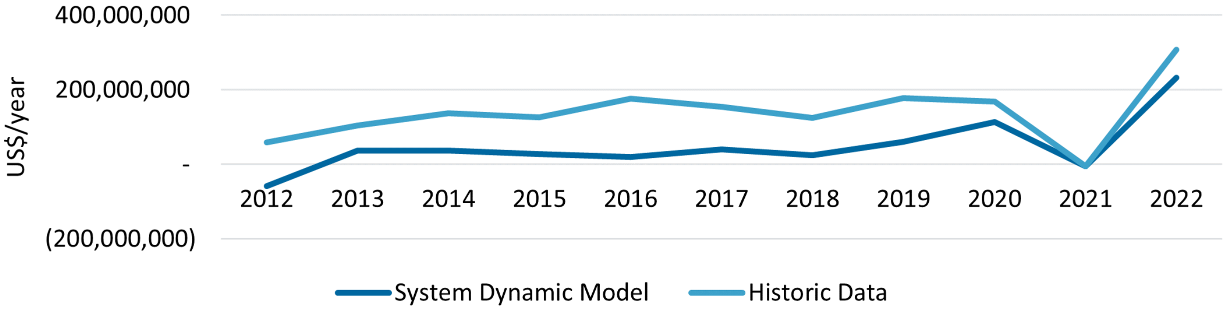

Figure 3.19: Processor Net Income Historic Comparison

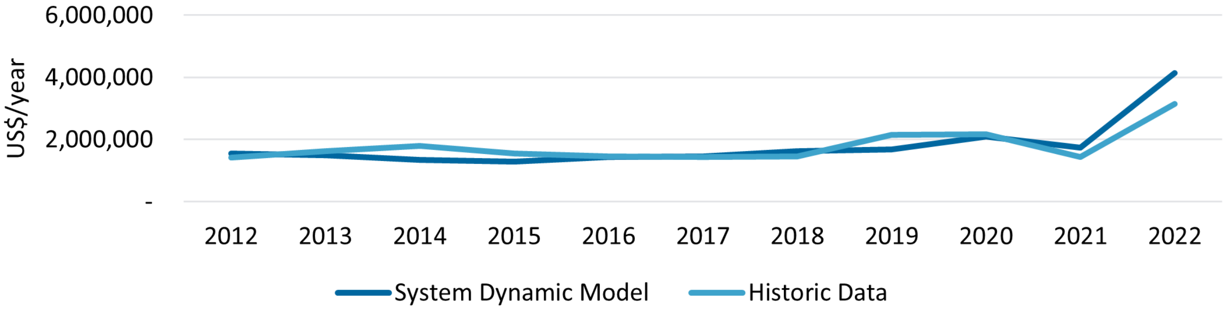

Figure 3.20: Oil Trader Net Income Historic Comparison

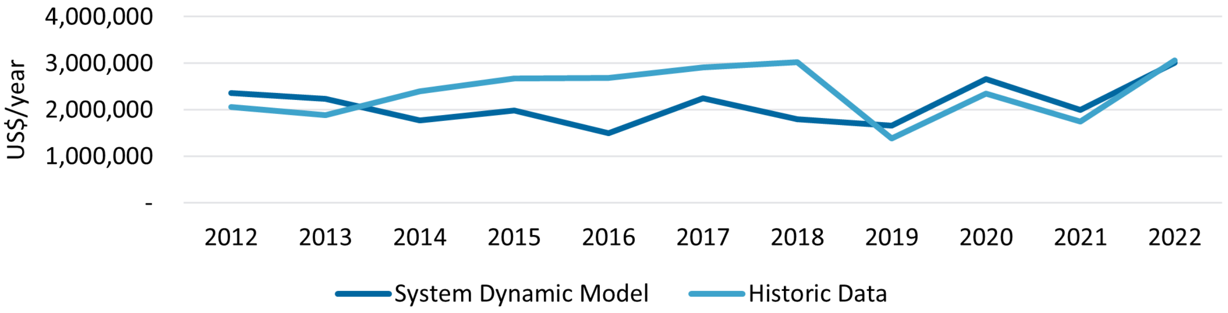

Figure 3.21: Cake Trader Net Income Historic Comparison

Optimisation Model Behaviour Validation

The final scenario on the system dynamic model is to determine the ideal seed processed by oilseed processors to maximise the net income of the entire value chain. The optimisation model was verified by inserting the solution of the optimisation model, namely the ideal amount of seed to be processed, into the base system dynamic model (the model developed to represent the historic Tanzanian sunflower value chain from 2012 to 2022). The total net income of the entire value chain determined by the optimisation experiment equalled the total value chain net income in the base system dynamic model once the ideal seed processing volume was inserted. This verified that the optimisation experiment yielded the same solution as the base system dynamic model, which is validated in Sections 3.4.1, 3.4.2, 3.4.3 and 3.4.4. Given that the optimisation experiment yielded the same solution as the base model, it can be assumed that the optimisation model's solution represents the best solution for the base system dynamic model that represents the Tanzanian sunflower value chain, given the specified input parameters.

Once it had been established that the optimisation experiment represents and is aligned with the system dynamic model, it was determined if the optimisation experiment provided the best possible solution for the modelled Tanzanian sunflower value chain. The value chain net income of the optimisation experiment's solution was compared to the historic base model net income under the current conditions, where the observed in-field seed volumes were processed. The optimisation experiment's net income was 1 billion US dollars higher than the base model, indicating that the optimisation model did indeed maximise the value chain net income under the specified current conditions, as the result is higher than the base. Some further random seed processing volumes were selected and inserted into the base system dynamic model to ensure that the optimisation model returns an approximate ideal solution. No better solutions were obtained. Thus, it can be assumed that the optimisation model's solution (which randomly iterates through 20% of the total sample points) provides an approximate ideal.

Furthermore, the optimisation model's behaviour was tested to ensure that the ideal solution changed when the parameters changed. This was done by changing each one of the input parameters, running the optimisation experiment, and observing if the ideal solution changed as the parameters changed, which it did. The ideal solution is expected to change with a change in parameters as the change in parameters creates a different current state with different trade-offs between the price and volume of seed, oil and cake.

3.4.4 Extreme Condition Test

The extreme condition test evaluates whether the model reacts how it should react when exposed to extreme situations. This ensures that the model is able to incorporate out-of-the-ordinary black swan events, and establishes confidence in the results (Sterman, 2000b). The model was tested against the following extreme conditions:

- Zero local seed production
- Negative processor gross margin
- Cheaper imported seed

- Zero local oil and cake demand
- Constant local oil and cake demand
- Constant world oil and cake price

To ensure that the extreme condition tests covered the range of possible scenarios in the value chain, an extreme condition test was executed for each node in the value chain to test that a change at each node had an impact on the value chain and that the model reacted correctly. At the production node, the volumes were set to zero as an extreme conditions test, the ”Negative processor gross margin” and ”Cheaper imported seed” scenarios represented the processing node, and the ”Zero local oil and cake demand”, ”Constant local oil and cake demand” and the ”Constant world oil and cake price” scenarios represented the market node. No extreme condition test was executed that represents the trade nodes, as the traders follow the production, processing and market nodes and do not have fundamental levers of change to be studied in this project.

The optimisation model was also tested under extreme conditions in Section 3.4.4 by determining the highest possible seed sales and validating that the maximum and minimum possible amount of seed to be processed did not return a better solution than the optimisation experiment solution.

Zero Local Seed Production Extreme Condition Test

The volumes of locally produced seed were made zero by setting the production trigger of the model to remain at zero throughout the year, as opposed to changing to one in the months of harvest. The value chain system responded by importing all required seed as seen in Figure 3.22 which illustrates a drastic increase in seed imports. The seed price increased slightly due to the low supply of seed, as expected with supply and demand dynamics (a decrease in volume, increases in price). However, because the price is also affected by the oil and cake prices, the seed price did not drop at the same rate.

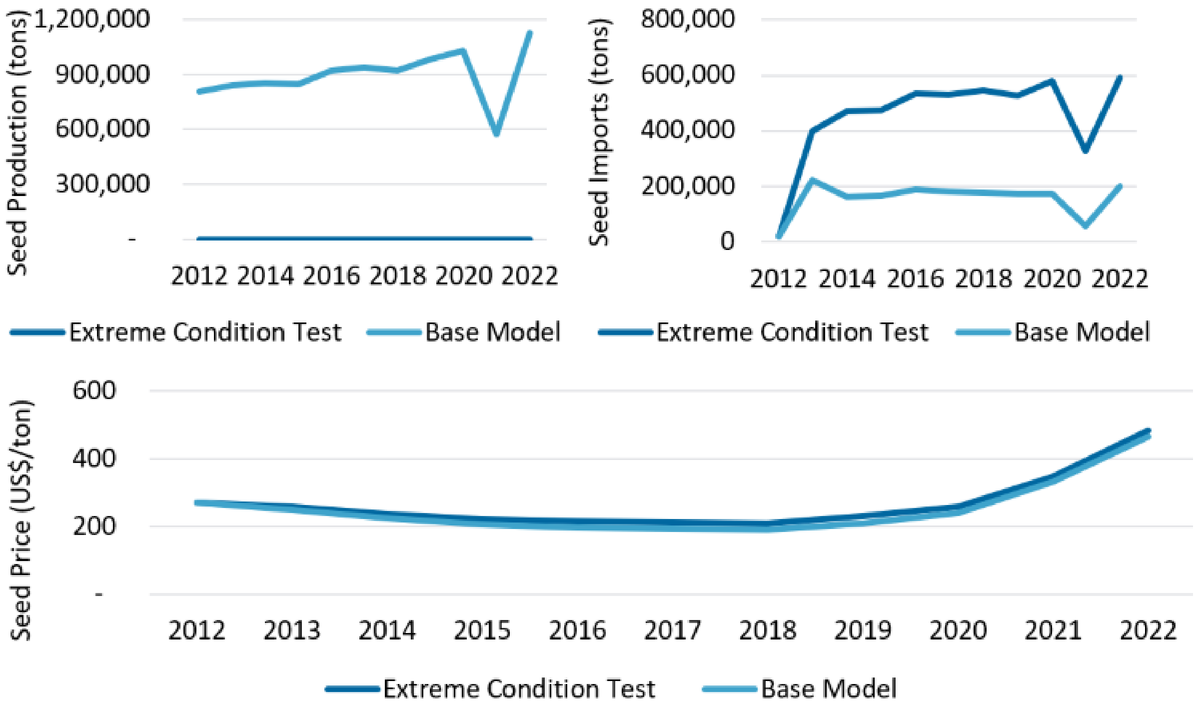

Figure 3.22: No Local Seed Production Test

Negative Processor Gross Margin Extreme Condition Test

The second extreme condition test adjusted the processor’s gross margin to be negative. This was imposed on the original processor’s gross margin and the processor’s gross margin by removing the by-product revenue when processing local and imported seed. The system realised that producing seed locally was financially unsustainable and over time increased the imported oil instead of producing the required oil locally, reducing local oil production. The reaction reflects the fact that processors cannot afford to operate at a loss.

The system's reaction is in line with the expected decision-making of consumers, which would prefer cheaper imported oil, than more expensive locally produced oil. Unless a mechanism is put in place by policy-makers to promote locally produced oil and the local economy, for example, an import tariff. An import tariff would make imported oil more expensive and bring imported oil to the same cost level as locally-produced oil, making locally-produced oil more competitive, driving up processor revenue and making gross margins profitable.

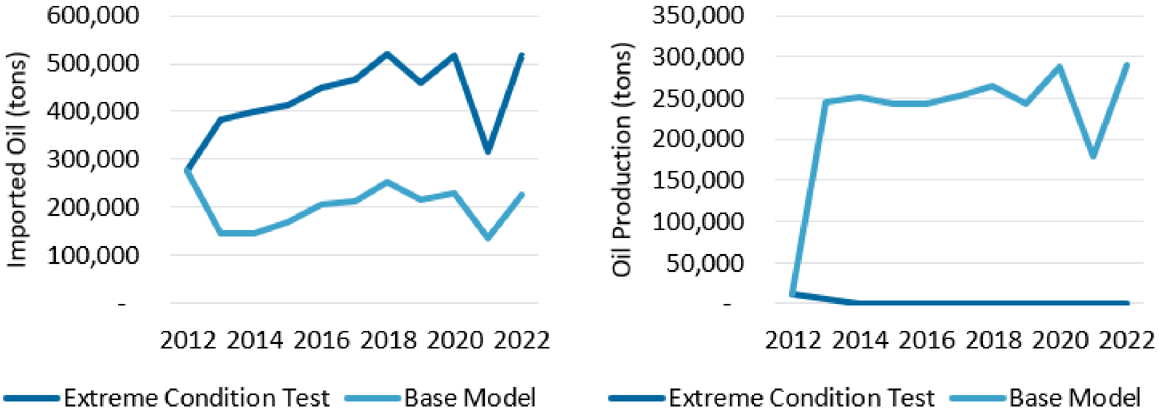

Figure 3.23: Negative Processor Profitability Test

Cheaper Imported Seed Extreme Condition Test

If it is assumed that the imported sunflower seed price is equal to the local sunflower seed price (by reducing the imported oil price), the system reacted by increasing seed imports and seed processing volumes. The reason for the increase is that the lower seed price (as all seeds can be purchased at a cheaper price) increased the processor's gross margin, which in turn increased the seed purchases and processing volumes. The increase in the processor's gross margin also increased the local seed production, and because local seed production is delayed, the seed is imported to replace the required seed.

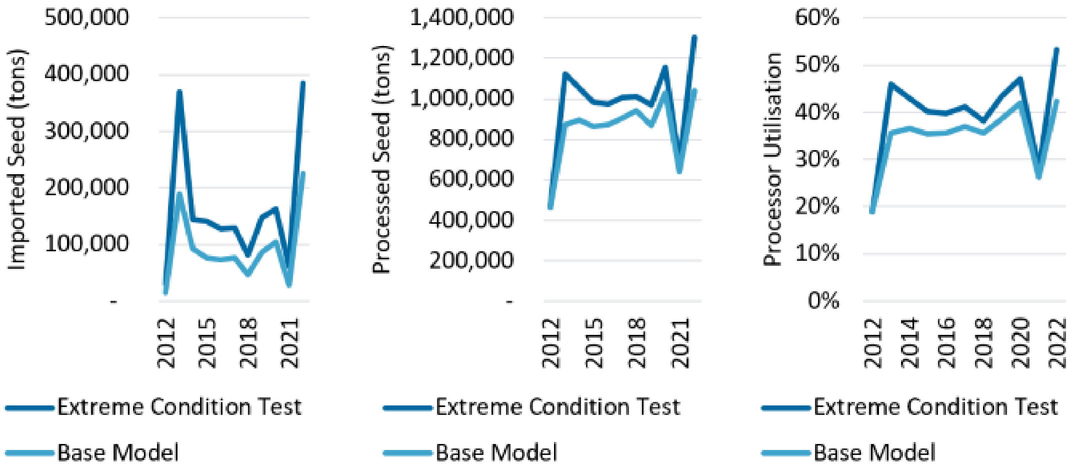

Figure 3.24: Decreased Seed Import Price Test

Zero Local Oil and Cake Demand Extreme Condition Test

For the fourth extreme condition test, the original oil and cake demand was assumed to be zero, forcing the system to export all locally produced oil and cake. Because the extreme test specified that there was no local oil demand, the oil imports dropped to zero. This extreme scenario tested the model's net trade formulation by ensuring that the model does indeed export the additional products produced as expected and required.

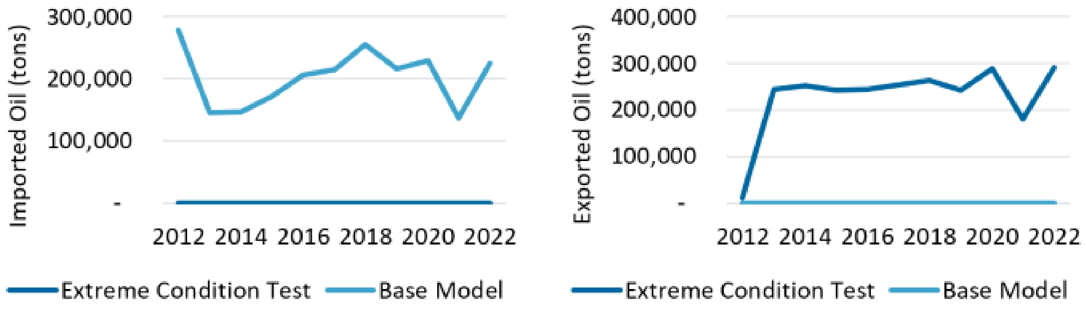

Figure 3.25: No Local Product Demand Test

Constant Oil and Cake Demand Extreme Condition Test

To model a constant oil and cake demand, the population was set to stay constant. Thus gradually decreased oil imports and increased cake exports as the product production increased but the demand stayed constant. This test illustrated that dynamics between supply and demand and trade to ensure that the additional volumes move through the correct channels as expected. The local demand for oil and cake is not a straight line (as expected if the population remains constant), because the demand is also affected by the sunflower seed yield.

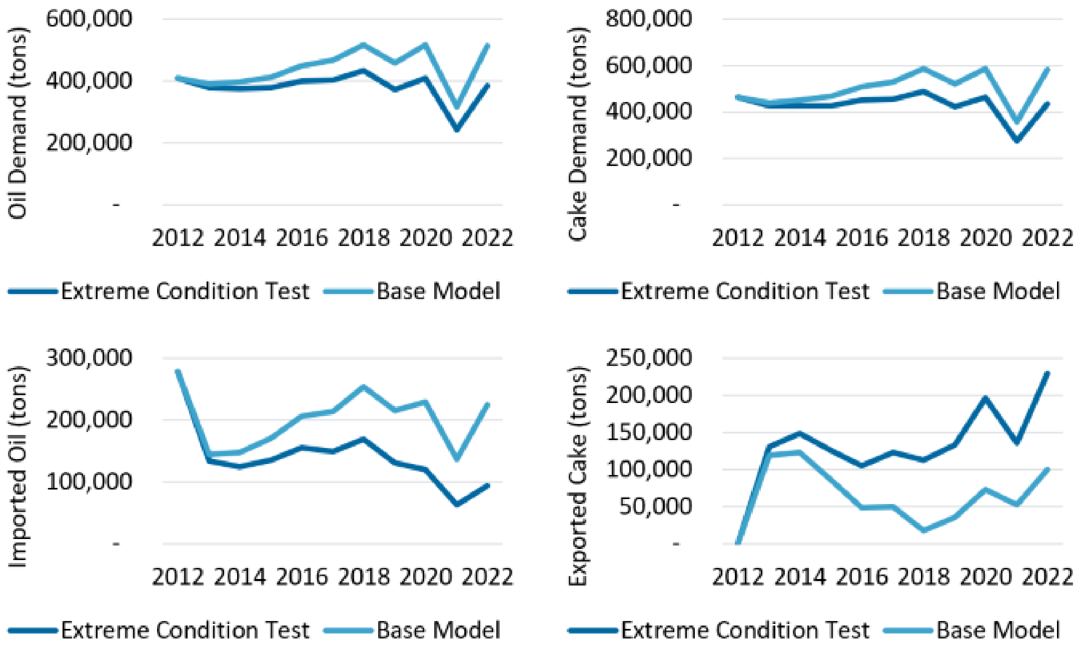

Figure 3.26: Constant Population Test

Constant World Oil and Cake Price Extreme Condition Test

Finally, the world oil and cake prices were kept constant (instead of changing over time with an input variable), to check that all prices remained constant as required and no other variable impacted the local prices where no variables should. Figure 3.27 illustrates that the oil and cake prices remained constant. However, the seed price varied slightly due to the impact that seed production volumes have on the seed price.

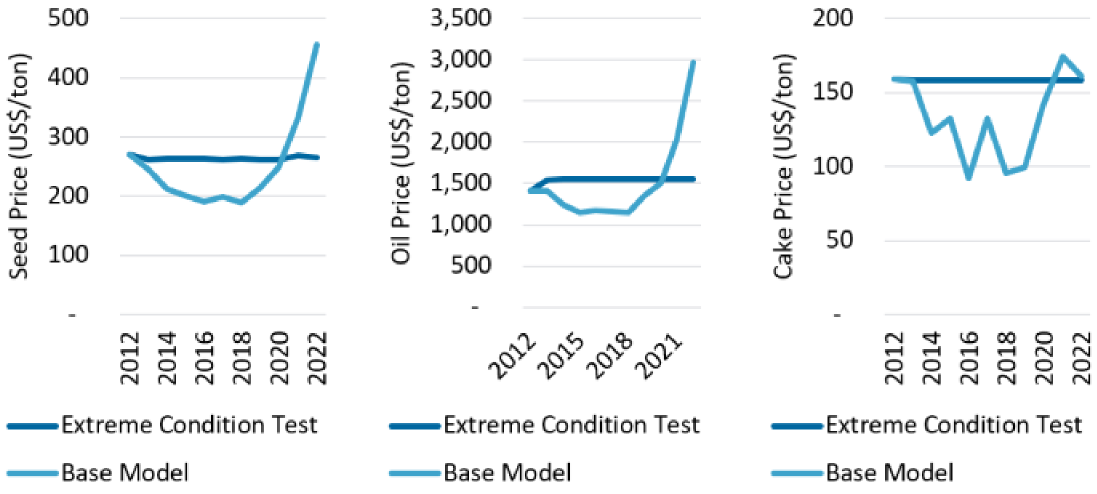

Figure 3.27: Constant World Price Test

Optimisation Model Extreme Condition Test

The optimisation model went through model validation by testing if the model returned the highest possible seed sales if it was assumed that processors paid the same price for imported seed as for locally produced seed and if only the processor net income was maximised over the time period. The processor's capacity (2,450,000 tons per year or 204,166 per month) was returned, as the trade-off between seed price and volume became obsolete because the local and imported price was set to be the same. The optimisation model's results illustrated that to achieve the maximum net income for processors, the maximum seed sales should occur, which are equal to the total Tanzanian sunflower processing capacity of 2,450,000 tons per year.

The results of the optimisation model were further validated by stating that the original seed processed was equal to the maximum and minimum (both sides of the extreme) amount of seed possible to be processed when maximising the total value chain net income. Thus, a simulation was run of the Tanzanian sunflower value chain model by stating that the seed processing volume in 2012 was equal to 204,166 (the monthly processing capacity in Tanzania) and again when setting the seed processing volume in 2012 to one (not equal to zero because zero made the model inoperable because the value is used further on in calculation). For both the minimum and maximum scenario, the total value chain net income was lower than the ideal solution (minimum seed processing scenario: -1 billion US dollars; maximum seed processing scenario: -4 billion US dollars), and even lower than the base model representing the historic state. The results supported the optimisation results by showing that no better solution could have been obtained.

3.5 Model Development Conclusion

The system dynamic model of the Tanzanian sunflower value chain was developed with the steps discussed in the literature review and specified by Sterman (2000a). The Tanzanian sunflower value chain environment and background were discussed. The problem was defined by discussing the Tanzanian sunflower value chain and briefly analysing historic production and consumption data. The problem was illustrated with a quick calculation of the impact that different levels of processor seed availability would have on each node of the value chain. This analysis illustrated that processors would have the biggest impact due to their high overhead costs.

Once the problem background and objective were understood, the sunflower value chain system was defined with the dynamic hypothesis and the causal loop diagram. The causal loop diagram was developed from the dynamic hypothesis, the generic value chain structure illustrated in Figure 3.3, supply and demand principals (Smith, 2010), a basic crop partial equilibrium model, as well as the International Model for Policy Analysis of Agricultural Commodities and Trade Model developed by

Rosegrant et al. (2008), and referring to the Tanzanian sunflower partial equilibrium model developed by BFAP (2022).

The causal loop diagram was developed, from which the mathematical formulation was constructed, together with the data analysis in Section 3.2.2, after which the model was run. The results of the model were compared to the gathered and validated historical data (representing 2012 to 2022). If the model did not align with the historical data, the process was repeated by adjusting the causal loop diagram, adjusting the formulation, re-running the model and comparing the model results, until the model accurately aligned with the historical data.

From the model verification and validation, it was established that the model represented the real Tanzanian sunflower value chain by conducting the boundary adequacy test, dimension consistency test, structural assessment test, behaviour reproductivity test or historic fit test, logical structural behaviour test, extreme conditions test and parameter validation. Given the model's accurate simulation of the historical data, and given that the model reacted correctly under the different verification and validation tests, it could be concluded that the model accurately represented the real Tanzanian sunflower industry and its black-swan events.

Additionally to the base system dynamic model, an optimisation experiment was developed which determined the ideal amount of seed to be purchased by processors to maximise the total value chain and processor net income. The optimisation model was validated and verified by checking if the optimum experiment yielded the same results as the base model, determining if the ideal solution result was truly the best and ensuring that the solution changed as the parameters changed. Furthermore, the optimisation model was tested under extreme conditions where the local and imported seed had the same price and where the original seed processing volume was set equal to the maximum and minimum possible levels. As with the base system dynamic model, the optimisation experiment passed all required validation and verification tests, establishing confidence in the Tanzanian value chain system dynamic model and optimisation system dynamic model.

Tanzanian Sunflower System Dynamic Model Results and Discussion

The goal of this project is to evaluate the impact of a change in available processor seed volumes on the entire value chain's financial sustainability. This is done by analysing the financial sustainability of the value chain when increasing and decreasing the volume of seed available at the processing node. The impact is further evaluated by considering different seed sources (local or imported). Finally, the analysis determines the ideal processor seed purchasing level for maximising value chain net income to provide insight into the decision-making of value chain stakeholders.

Before analysing and discussing the results in Section 4.3, the changes imposed on the model are discussed in Section 4.2 to simulate the different scenarios explained in Section 4.1.

4.1 Scenario Simulations

To achieve the goal of this project, four scenarios were executed with the Tanzanian system dynamic value chain model developed in Chapter 3, as listed and discussed below. Each scenario has a different objective and is analysed with multiple scenario executions (for example, Scenario 1 was analysed by running the model five times and comparing the results, while the optimisation experiment for Scenario 4 simulated 50,000 iterations). For each model execution the prices, volumes and costs were captured over time, as well as the gross margin and net income for all nodes in the value chain was captured with the system dynamic model.

Base Model: The base model replicated the current state in 2022 and projected into the future (2022 to 2032), illustrating the prices, costs, volumes, gross margins and net income for each year. It is crucial to have a baseline to compare the different scenarios to, and analyse the difference due to the changes imposed by the scenarios.

Scenario 1: The decreased local seed supply scenario illustrates the effect of limited raw material seed on the value chain net income and financial sustainability. Available seed is reduced by assuming lower yields in increments of 10%, throughout the entire modelled period (2022-2032), while not importing seed because the seed import prices are uncompetitive and high. Quantifying the impact assists the industry in comparing the costs and losses of different limited raw material availability levels and assists in developing contingency plans for prevention and management. Thus quantifying how much is lost, informs how much can be spent to prevent the loss while not going beyond what could potentially be lost (the benefit if it is not lost).

Scenario 2: The increased local seed supply scenario looks at how the value chain reacts if the seed-producing yield is increased, by assuming that an investment is made into seed development that significantly improves yields (by 10% to 50%), like introducing hybrid seed varieties. This scenario is important to illustrate the positive effect of investing in the value chain, as opposed to the negative impact of limited seed availability discussed in Scenario 1. Furthermore, the scenario identifies possible bottlenecks or potential improvement areas to accommodate the additional volumes moving through the value chain.

Scenario 3: The source comparison scenario considers two different sourcing strategies. The scenario assumes that a) seed cannot be imported, driving down processor utilisation (as in Scenario 1), or b) seed can be imported to replace the required lost seed but at a higher imported seed price. The imported seed scenario was selected because importing raw materials is the quickest way to mitigate the raw material shortage problem. The scenario evaluates the impact that a structural change (like raw material sourcing) can have on the value chain sustainability.

Scenario 4: The optimisation scenario determines the ideal volume of seed to be purchased by processors to maximise the total value chain net income (including seed producers, seed traders, oil traders, cake traders and processors). The ideal volume is not merely the maximum volume of seed available for processing, because there is a trade-off between paying extra for imported seed and saving costs due to a higher utilisation for the processing facility.

Due to the inverse relationship between price and volume (illustrated in Figure 4.1), processors may purchase less seed because purchasing more seed may result in an increase in seed prices. This is supported by the supply and demand principal (Smith, 2010) and through the R-loop in the causal loop diagram in Figure 3.7, where a decrease in the seed price has a negative impact on the area under production, which in turn has a positive impact on the seed price.

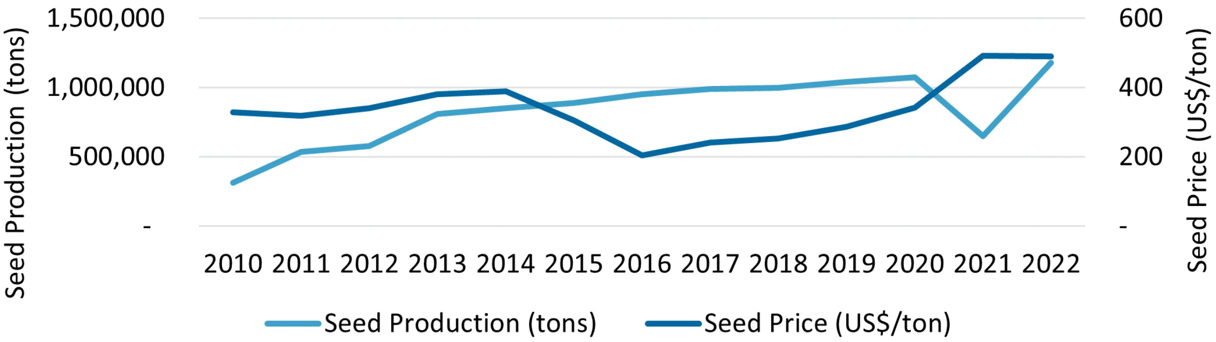

Figure 4.1: Seed Production and Seed Price Relationship

Source: (FAOSTAT, 2022; Tanzania Ministry of Agriculture, 2022)

The system dynamic model does not take into consideration the fact that processors may decide not to purchase imported seed or even locally produced seed, because it does not make financial sense (if they make a loss when purchasing and processing). The model merely reduces the amount of seed purchased for processing as the processor profitability performs poorer. However, the ideal seed processed for maximum returns may differ from the volumes projected by the model according to processor history and profitability. The optimisation model sets out to capture this.

The optimisation scenario assists in determining what is the ideal amount of seed to be purchased by processors to maximise the value chain net income. The second optimisation scenario looks at how much seed processors should purchase to maximise their own profitability. This scenario assists in understanding when processors would purchase imported seed and how the objective of the processors aligns with the overall improvement of the value chain financial sustainability.

Finding the ideal assists in understanding how much local seed production is required to make processors and the value chain as profitable as possible, thus uplifting the value chain. The optimisation scenario is crucial to understand what is required to achieve an upgraded state of the industry. Often interventions promote volume increases, while further interventions are required to support the volume increase to be handled downstream of the value chain. Running the optimisation model and the basic system dynamic model together can assist in identifying the ideal state, interventions to achieve the ideal state, and bottlenecks that prevent the ideal state from realising.

4.2 Base Model Adjustments and Scenario Implementation

4.2.1 Base Model Adjustments

Once confidence was established in the model that represented the historic ten years of the Tanzanian sunflower value chain, by going through rigorous verification and validation as discussed in Section 3.4, the projected base model was developed which represents the years 2022 to 2032. Given the model's rigorous verification and validation that proved that the model accurately represented the Tanzanian sunflower value chain, as well as the value chain under different extreme conditions (as the validation and verification process included extreme scenarios simulating different black-swan events, dimensional consistency test, boundary adequacy test, structural and logical behaviour test and data verification), it was assumed that the model could be used to accurately represent the future ten years as well.

The model was adjusted to represent the future ten years as nothing can be done about the past, but understanding how different scenarios may affect the future can assist in planning for the future. However, projecting into the future carries more uncertainty and less assurance that the model is accurate, as any unexpected events may occur. Thus, it is important that all scenarios run across the same time period for a valid comparison.

The base model assumes that the future will react as the last ten years without any black swan events (any extraordinary events that affect the future in an uncontrollable manner), but with different input parameters that represent the future ten years. Given that the model needs to project the next ten years, the model run time was changed from the 2012 to 2022 time period, to the 2022 to 2032 time period. The parameters were changed to 2022 values (instead of 2012 as in Table 3.2 Section 3.3.3) as listed in Table 4.1. All the input tables of the model were updated to represent future yield, inflation, population and world prices from 2022 to 2032.

Table 4.1: Parameter Estimation for Future Base Model

Parameter on AnyLogic Stock-flow Diagram	**Parameter in Mathematical Formulation**	**Unit**	**2022**	**Data Source**	**Changing Input Variable Source**
Original Seed Produced	S_b	tons	1,176,990	(Tanzania Ministry of Agriculture, 2022)	
Original Production Area	a	hectare	1,566,000	(Tanzania Ministry of Agriculture, 2022)	
Yield	y	ton/ha	0.75	(Tanzania Ministry of Agriculture, 2022)	(OECD, 2023)
Original Seed Sales	S_c	tons	814,000	In-field data gathering by BFAP (2022)	
Original Oil Produced	O_b	tons	248,265	In-field data gathering by BFAP (2022)	
Original Cake Produced	C_b	tons	573,149	In-field data gathering by BFAP (2022)	
Oil Extraction Rate	E_o	%	28	In-field data gathering by BFAP (2022)	
Cake Extraction Rate	E_c	%	64	In-field data gathering by BFAP (2022)	
Original Oil Demand	O_c	tons	682,913	In-field data gathering by BFAP (2022)	
Original Cake Demand	C_c	tons	573,149	In-field data gathering by BFAP (2022)	
Original Seed Price	P_s	USD/ton	538	(Tanzania Ministry of Agriculture, 2022)	
Original Oil Price	P_o	USD/ton	2,352	(Tanzania Ministry of Agriculture, 2022)	
Original Cake Price	P_c	USD/ton	197	In-field data gathering by BFAP (2022)	
World Seed Price	P_{si}	USD/ton	1,090	(FAPRI, 2023)	(FAPRI, 2023)
World Oil Price	P_{oi}	USD/ton	3,098	(FAPRI, 2023)	(FAPRI, 2023)
World Palm Oil Price	P_{oip}	USD/ton	2,290	(FAPRI, 2023)	(FAPRI, 2023)
World Cake Price	P_{ci}	USD/ton	177	(FAPRI, 2023)	(FAPRI, 2023)
Original Producer Variable Cost	C_{sv}	USD/ton	151	In-field data gathering by BFAP (2022)	
Original Producer Fixed Cost	C_{sf}	USD/ton	50	In-field data gathering by BFAP (2022)	
Original By-product Price of Producers	Q_s	USD/ton	100	In-field data gathering by BFAP (2022)	
Original Processor Variable Cost	C_{cv}	USD/ton	90	In-field data gathering by BFAP (2022)	
Original Processor Fixed Cost	C_{cf}	USD/ton	61	In-field data gathering by BFAP (2022)	
Original By-product Price of Processors	P_w	USD/ton	100	In-field data gathering by BFAP (2022)	
Population	k	people	60,382,750	(United Nations, 2023)	(United Nations, 2023)
Crusher Capacity	v	tons	2,450,0000	In-field data gathering by BFAP (2022)	
Weight: Historic Area to Area	$w_{a(0)a(t)}$	%	37.8	Data correlation analysis Section 3.2.2	
Weight: Seed Price to Area	$w_{P_{s(t)}a(t)}$	%	50	Data correlation analysis Section 3.2.2	
Weight: Seed Processed to Area	$w_{s_c a(t)}$	%	39.7	Data correlation analysis Section 3.2.2	
Weight: Seed Producion to Seed Price	$w_{s_b P_s}$	%	-20	Data correlation analysis Section 3.2.2	
Weight: Product Price	w_{P_s}	%	75	Data correlation analysis Section 3.2.2	
Weight: World Oil Price to Oil Price	w_{po}	%	51.4	Data correlation analysis Section 3.2.2	
Weight: Palm Oil Price to Oil Price	w_{ppo}	%	62.5	Data correlation analysis Section 3.2.2	
Weight: World Cake Price to Cake Price	w_{P_c}	%	100	Data correlation analysis Section 3.2.2	
Market Share: Seed Trader	l_{st}	%	20	Data correlation analysis Section 3.2.2	
Profit Markup: Seed Trader	r_{st}	%	12	Data correlation analysis Section 3.2.2	
Market Share: Oil Trader	l_{ot}	%	3	Data correlation analysis Section 3.2.2	
Profit Markup: Oil Trader	r_{ot}	%	9	Data correlation analysis Section 3.2.2	
Market Share: Cake Trader	l_{ct}	%	20	Data correlation analysis Section 3.2.2	
Profit Markup: Cake Trader	r_{ot}	%	16	Data correlation analysis Section 3.2.2	
Constant: 1	z_1		1.3	Data correlation analysis Section 3.2.2	
Constant: 2	z_2		1.2	Data correlation analysis Section 3.2.2	
Constant: 3	z_3		1.1	Data correlation analysis Section 3.2.2	
Inflation	I		194	(International Monetary Fund, 2023)	(International Monetary Fund, 2023)

The model is assumed to act as the last ten years, however, one structural change is expected, as Tanzania's dependency on subsistence farming is expected to decrease due to urbanisation. The World Bank (2023) projects that more than half of the population of Tanzania will live in cities by 2030, and no longer in rural areas. If fewer people live in rural areas, fewer people can produce their own food under subsistence farming. For this reason, the link between yield and seed demand was removed in the base model scenario analysis (the link is highlighted in red in the causal loop diagram in Figure 4.2), as this link assumes that the seed demand changes as the yield changes. Figure 4.3 illustrates the same structural change imposed on the AnyLogic stock-flow model, by removing the feedback loop between "Yield" and "Seed Sales".

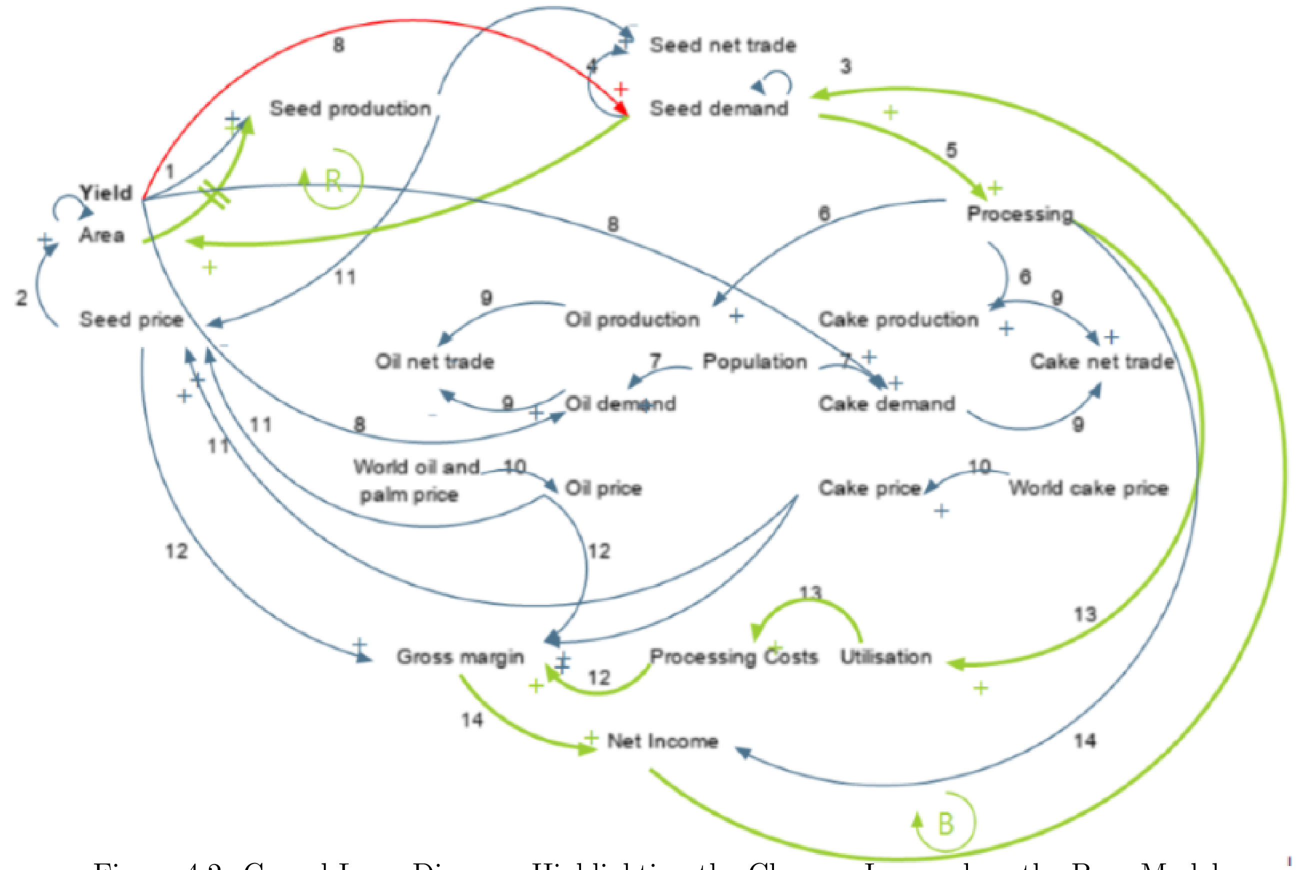

Figure 4.2: Causal Loop Diagram Highlighting the Changes Imposed on the Base Model

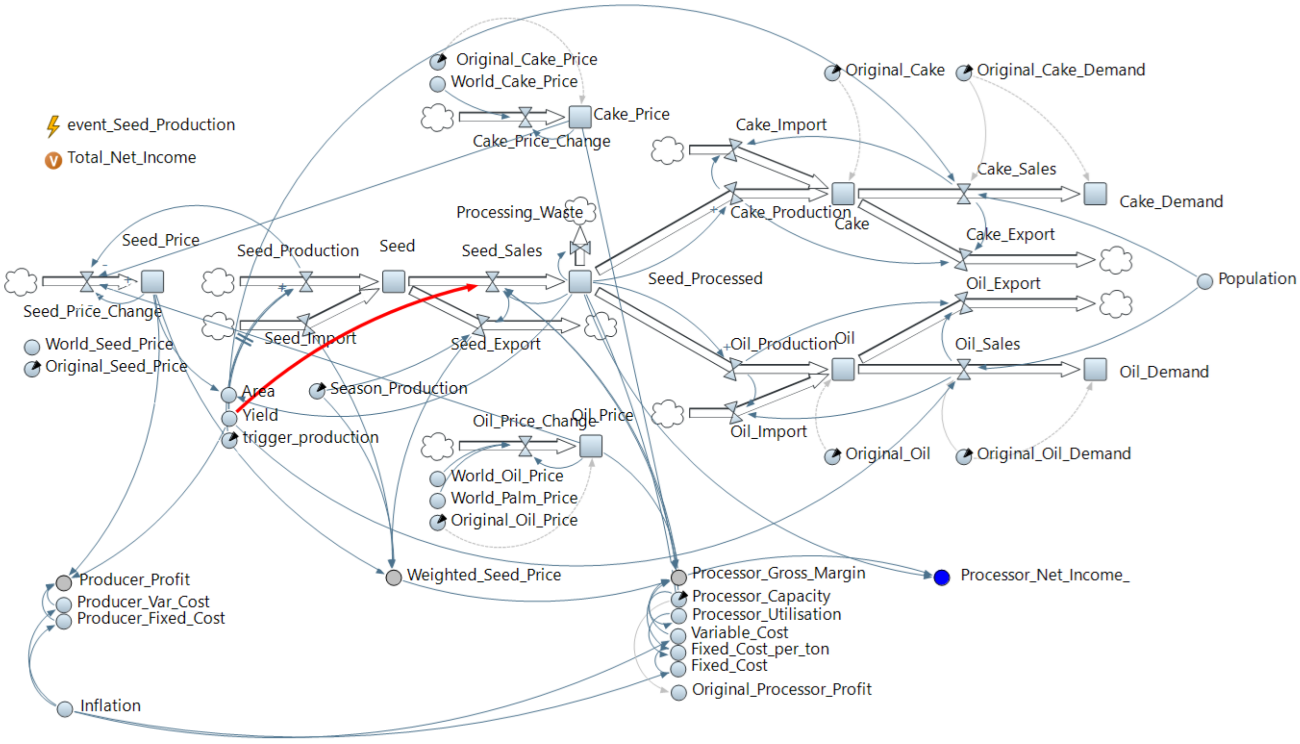

Figure 4.3: Basic Stock-flow Diagram Highlighting the Changes Imposed on the Base Model

This change is implemented by removing the change in yield (included in the base historic model in Equation 3.6) and calculating the seed purchases ($S_c(t)$) as calculated in Equation 4.1 by merely adding historic seed processed ($S_c(t-1)$) multiplied by the weight (w_{sc}) to the processor margin index ($MI_c(t)$), which is multiplied by the original processor margin ($M_c(0)$) and constant (z_1).

$$S_c(t) = max\left(min(w_{sc}S_c(t-1) + MI_c(t)M_c(0)z_1, v), 1\right) \tag{4.1}$$

The adjusted projected base model can not be validated and verified as it projects into the future which is uncertain and has no benchmark to be compared to. However, given that the historic model was validated and verified in Section 3.4, and only the one structural change was implemented and the input data (listed in Table 4.1 and validated in Section 3.4.1) was updated, the projected base model was assumed to be accurate.

The model was run monthly to capture the cyclic behaviour of the Tanzanian sunflower value chain due to seed production only occurring during two months of the year when harvesting. The volume, price, costs, gross margins and net income are captured every month, however, the model was analysed annually and over the entire ten years (2022 to 2032), as the total value chain impact is of interest which represents a more high-level analysis. Running the model monthly ensures that the calculated net income of the model is more accurate by calculating a weighted average and not an overall average. For example, by running the model monthly, the cost of seed purchased by processors is equal to the volume of seed purchased per month multiplied by the price of seed in each specific month, summed over the twelve months per year and summed over the ten years modelled. If the model was not run monthly, the seed purchases of processors would have been equal to the total volume purchased each year multiplied by the average seed price across the year (giving each month's price the same weight, as opposed to giving the months' where more seed was purchased, a higher weight).

4.2.2 Scenario Implementation

A summary of the changes imposed on the base model to simulate the scenarios is listed in Table 4.2. All the changes for the scenarios were imposed on the yield dynamic variable, as well as the seed import and seed sales flow as highlighted in red in Figure 4.4.

Table 4.2: Scenario Changes Implemented

Scenario	**Changes Implemented**
Scenario 1: Decreased Local Seed Supply Scenario	Seed traded was set equal to zero (do not import seed)
	Updated seed sales formula as in Equation 4.2
	Input yield was adjusted downwards by 10%, 20%, 30%, 40% and 50%
Scenario 2: Increased Local Seed Supply Scenario	Input yield was adjusted upwards by by 10%, 20%, 30%, 40% and 50%
Scenario 3: Source Comparison	Seed was imported and not imported with Equations 3.6 and 4.2
	Input yield was adjusted downwards by 10%, 20%, 30%, 40% and 50%
Scenario 4: Value Chain Optimisation	Create optimisation scenario
	Fix all parameters, except for the seed sales purchased by processors

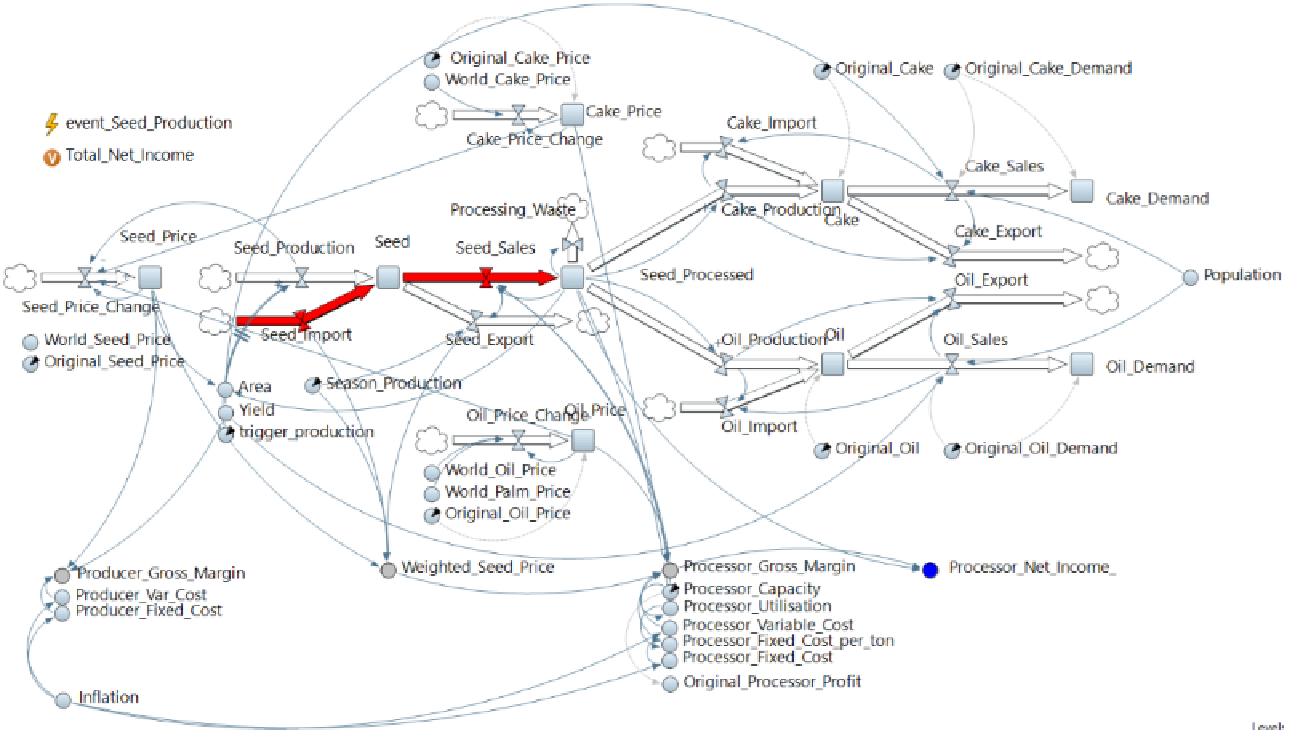

Figure 4.4: Stock-flow Diagram highlighting the Scenario Changes

Scenario 1: To illustrate the impact that a range of limited seed would have on the value chain, the realised yield throughout the time period was adjusted downwards by 10%, 20%, 30%, 40% and 50% by multiplying the yield in the expected input table by the respective decrease (multiplying by 0.9 for a 10% decrease and multiplying by 0.8 for a 20% decrease etcetera).

Simultaneously, the seed imports were kept at zero by replacing the seed import formula (Equation 3.4) with "0" and replacing the seed sales equation (Equation 3.6) with Equation 4.2, which forces the seed sales not to exceed the locally available seed (S_b), thus not allowing imports to replace the reduced local seed supply and ensuring that a truly limited seed scenario is represented. Preventing seed imports is required as the model does not include a decision variable that prevents seed imports if the imported seed is too expensive. Rather, the model adjusts the seed purchases downwards as the gross margin decreases due to high imported seed costs. It is assumed that no backlog orders can occur, but stock can be carried over and only processed in the next year. The new seed sales formula ensured that the minimum of the seed demand or seed processing capacity (v) or seed produced (S_b), was sold. This ensured that the maximum amount of seed sold, was the amount of seed produced in the year.

$$S_c(t) = min\Big(min(w_{sc}S_c(t-1) + MI_c(t)M_c(0)z_1, v), S_b\Big) \tag{4.2}$$

Scenario 2: The impact that a higher seed availability can have on the value chain was measured in Scenario 2 by multiplying the yield in the expected yield table by 1.1, 1.2, 1.3, 1.4 and 1.5 to illustrate a 10%, 20%, 30%, 40% and 50% increase in seed availability. The rest of the model was kept as in the base model, where the seed was imported.

Scenario 3: To analyse the impact of different seed sources (locally sourced or imported seed), the model was set back to normal by allowing imports and adjusting the realised yield downwards by 10%, 20%, 30%, 40% and 50% to be compared with Scenario 1 (where the seed was not imported).

Scenario 4: Finally, an optimisation scenario was created in AnyLogic, where all parameters were kept constant except for the volumes of seed purchased by processors, which was set to be larger than zero (as no negative seed purchases are possible, which would be seed sales, which are not included in this model) and smaller than the total Tanzanian sunflower processing capacity of 204,166 tons per month (2,450,000 tons per year). The model did 100 runs with random seeds, with 500 iterations through the range of seed purchasing volumes to maximise the total net income of the entire value chain. Another 100 random runs with 500 iterations were done while maximising the processor's net income.

4.3 Solution Evaluation

The aim of is project is to define the impact of a range of seed availability levels and sources (local compared to imported) on the value chain's financial sustainability. Net income is a primary agriculture sustainability indicator (Smith and McDonald, 1998), suitable to indicate the value chain financial sustainability and has been highlighted as an important indicator by Aramyan et al. (2007); Bowers (1995); Crowder and Reganold (2015); Valenti et al. (2011); Zhen and Routray (2003). This section analyses the different scenarios (including the base model) as discussed in Section 4.1 to determine the impact and feasibility of each scenario by unpacking the net income indicator.

4.3.1 Base Model Results

The total net income of the Tanzanian sunflower value chain across all nodes over the entire ten-year period is roughly US$ 11,241,000,000. The net income per node per year is illustrated in Figure 4.5.

As seen by the negative processor net income, 2022 was an abnormal year due to the Russia-Ukraine war and post-Covid-19 impacts (Elleby et al., 2020; Liadze et al., 2022), and can almost be excluded, but is kept to illustrate the model's ability to capture abnormal situations and black-swan events, for which simulation models are very suitable. Even though 2022 was abnormal and had massive implications that could not have been expected or modelled, it is part of history and should be included.

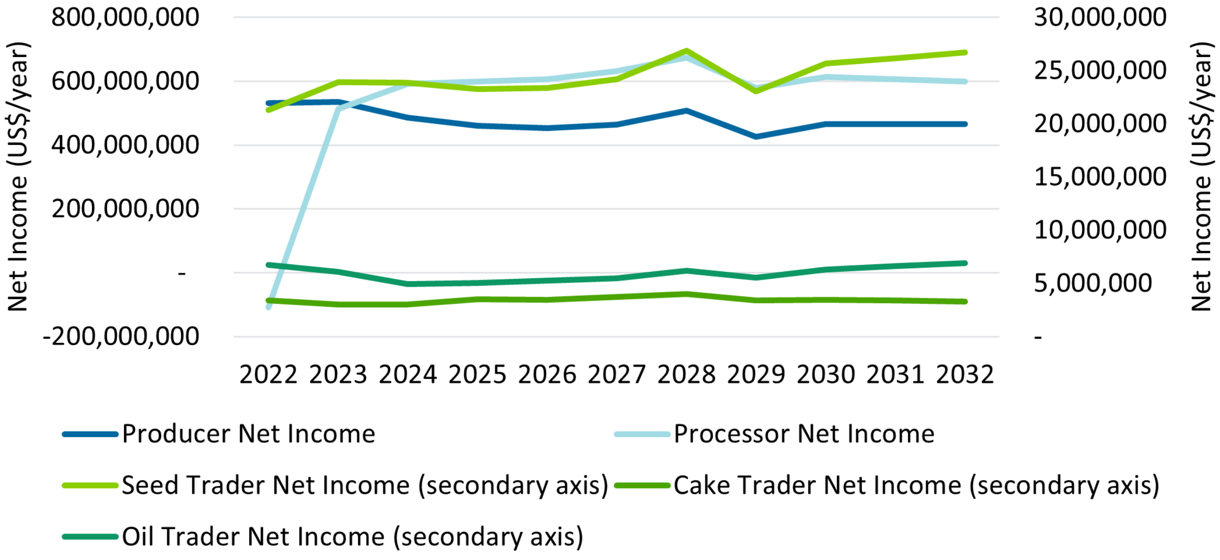

Figure 4.5: Base Scenario Net Income over Time

Because of the high local seed prices (due to limited global sunflower seed as a result of the war (Liadze et al., 2022)), the local sunflower production area is expected to increase significantly in 2023. This provides a potential for significant additional volumes of locally available seed, which causes the seed producer and trader net incomes to increase by 1% and 12% from 2022 to 2023. The increase in seed production is in turn expected to decrease the local seed price. After 2023, global oil and cake prices are expected to return to normal, gradually normalising the entire value chain (FAPRI, 2023). Because the seed price is expected to have a larger decline than oil and cake prices, the simulation illustrates that the processors will have a significant gross margin and net income gain (418%) from negative to positive levels from 2022 to 2023.

Over the entire ten-year period, producer profits are expected to decrease because the local seed price is expected to normalise and decrease by 47% from 2022 to 2032, after Covid-19 and after the sudden Russia-Ukrainian war impact (the war is not necessarily expected to end, but the world is expected to re-balance and adjust to the situation (FAPRI, 2023)). Similarly, the local oil prices are also projected to decrease by 36% from 2022 to 2032 and the cake price by 39% (imposed on the model through the input data). The decline in prices will contribute to all value chain nodes' net incomes remaining relatively flat over the period from 2023 to 2032, as the world tries to return back to normal (assuming that there are no further black swan events).

The net income of oil and cake traders is expected to follow the price and volume trends, as their volumes traded are not expected to change and their profit margin is expected to remain a percentage on top of the price of the product that they trade. According to the input data (FAPRI, 2023), in 2029 the world cake price is expected to drop, affecting the processor and cake trader net income, as well as the seed price and with it the seed producer and seed trader net income as illustrated in Figure 4.5.

As the local seed production increases over the time period, the exported seed is expected to increase as seen in Figure 4.6. The positive processor gross margin in 2023 is expected to increase the volume of seed purchased and processed by sunflower seed processors. As no event is expected to decrease the local sunflower seed production, and the world oil and cake prices, the processor gross margin is expected to remain positive and with it keep processing utilisation high (moving from 33% in 2022 to 100% in 2024). Due to the high and consistent local demand for sunflower seed, and the projected increase in yield due to new research and development (OECD, 2023), local seed production is expected to continue increasing beyond the local processing capacity, thus increasing seed exports.

Once again, the sudden kink in the seed processed in 2029 is due to the global cake price drop (FAPRI, 2023) affecting processor profitability and with it seed purchased for processing into oil and cake.

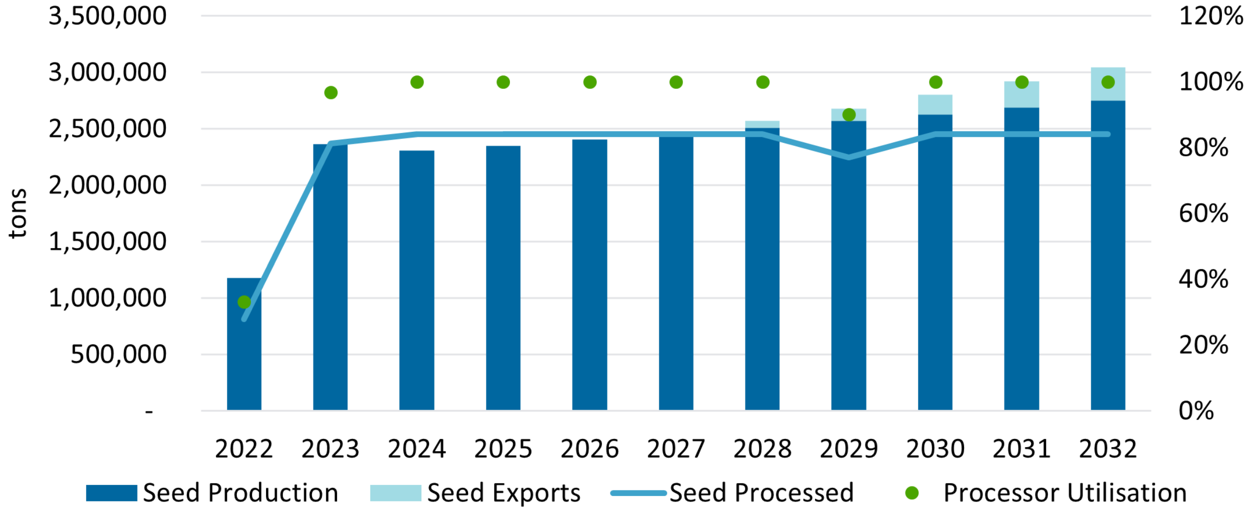

Figure 4.6: Base Model Seed Production, Traded and Processed with Processor Utilisation

4.3.2 Scenario 1: Decreased Local Seed Supply

The decreasing local seed supply scenario illustrates the effect of limited raw material seed on the value chain's financial sustainability. Available seed is reduced by assuming lower yields in increments of 10%, throughout the entire modelled period (2022-2032), while unable to import seed. Lower yields can be caused by multiple events that can often not be controlled, for example, a drought. The model scenario does not allow imports to ensure that the processed seed is in actual fact reduced and not replaced by imported seed.

The total net income of all nodes in the value chain at different seed availability levels is illustrated in Figure 4.7, with the percentage change of net income between the lower seed availability levels and the base model on the secondary axis and listed in the data labels. If the harvest decreases by 10%, thus if 10% less seed is available at the processing node, the total net income of the entire value chain is expected to be 19% lower than the net income in the base model. At a 20% decreased seed supply, the total net income is expected to be 37% lower than the base model's net income, and so forth. The non-linear change in total net income highlights the dynamic interactions of volumes, prices and costs that are at work in the model.

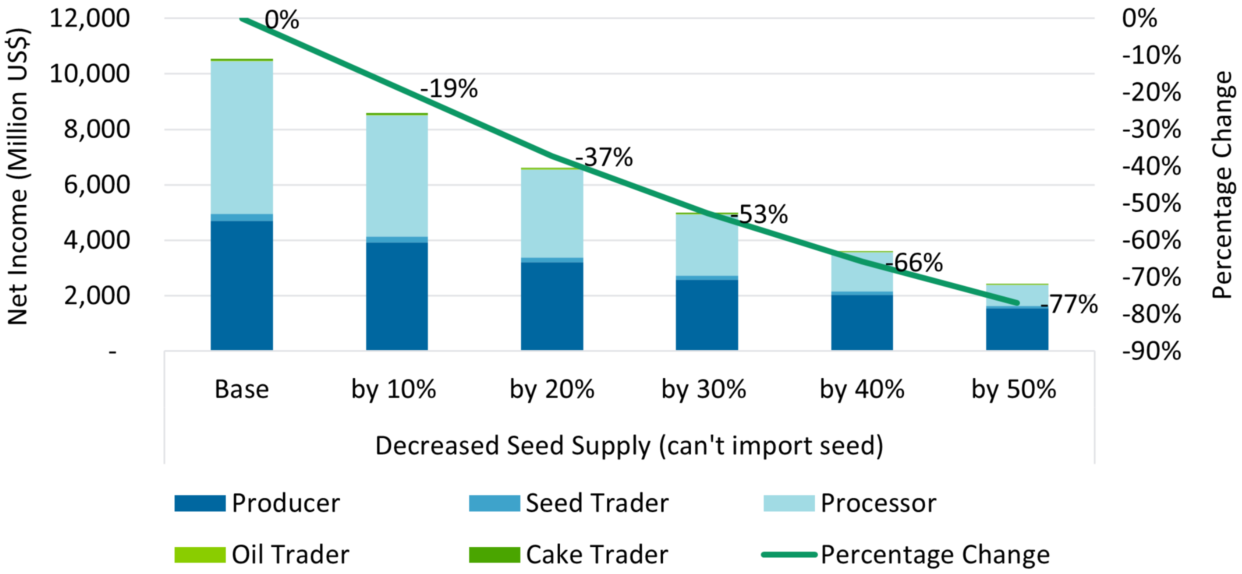

Figure 4.7: Decreased Local Seed Supply Net Income Effect

As expected, Figure 4.8 illustrates that the effects for the value chain nodes are larger than expected and illustrated in the high-level calculation conducted in the problem articulation (Section 3.1.2). According to the system dynamic model that includes indirect effects (like price changes), seed producers will lose 38% of net income when the yield drops by 20%, where the problem articulation calculation expected 25% (Figure 3.5), when compared to the base model where seed is imported. Seed traders lose 34% instead of 20%, processors 45% instead of 22%, and cake and oil traders 39% instead of 20%.

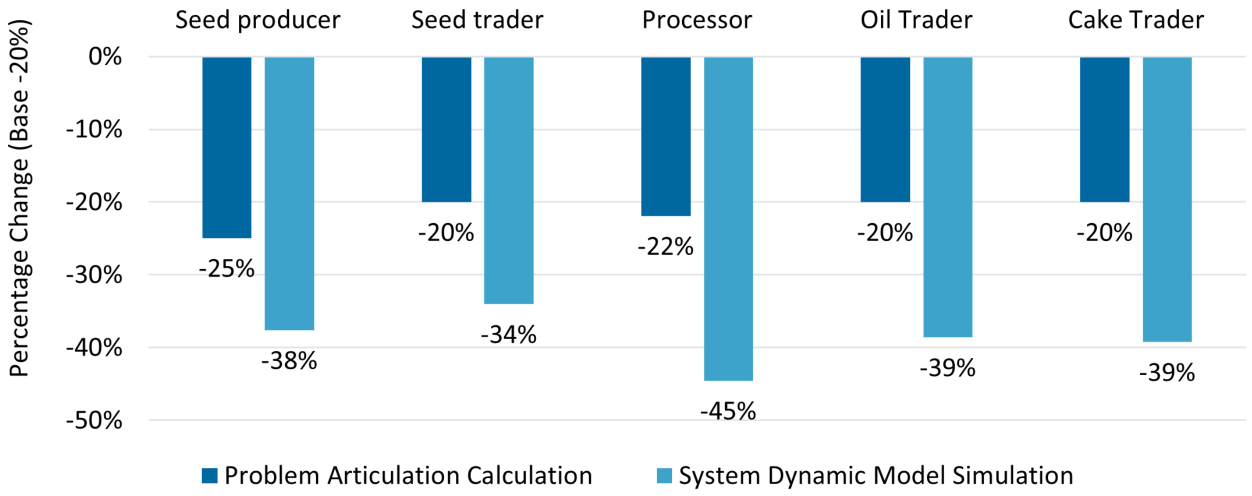

Figure 4.8: Comparison between Simple Calculation and System Dynamic Model at 20% Volume Loss

Figure 4.9 depicts the change in net income per seed availability level per node in the value chain. At a 10% decrease in seed volumes (compared to the base model where the seed is not imported), processors lose 21% of their net income, while seed producers lose 17%, and seed, oil and cake traders 14%. At an additional 10% seed decrease (at 20%), the impact is slightly lower, as the net income changes an additional 20% for processors, 15% for producers and 13% for traders.

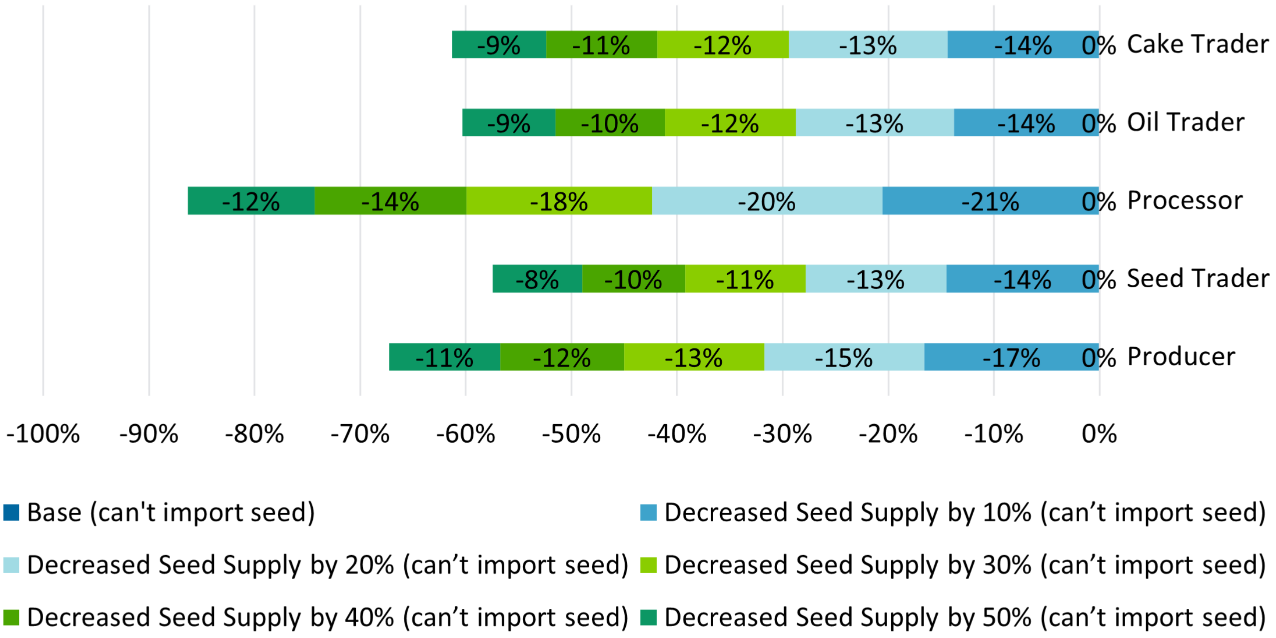

Figure 4.9: Decreased Local Seed Supply Net Income Percentage Change

The majority of the loss in net income occurs at the seed processor node, and secondly the seed producer node, because of the dynamics in the value chain. The large decrease in producers and processors is due to a combination of factors. Firstly, net income is lost due to the 10% loss in locally produced seed volume. Secondly, producers and processors have overhead costs that need to be incurred irrespective of the amount of seed that they produce or process. The overhead cost per ton increased, which decreased the gross margin per ton (illustrated in Figure 4.10), as the amount of seed produced and processed decreased. The processor's net income loss is higher than the producer's net income loss because of the processors' higher overhead costs. Thirdly, as the processor's gross margins decrease due to lower utilisation rates and higher overhead costs, the seed sales decrease at the rate illustrated in Figure 4.11 (as they are dependent on the processor's profitability), which in turn decreases the area under sunflower production and increases the seed price (illustrated in Figure 4.11).

Due to this combination of factors, the producer and processor net incomes decrease more than the seed volume decrease, with producers reaching a 67% net income loss and processors negative 86% at a 50% seed volume decrease (illustrated in Figure 4.9).

While on the other hand, the seed trader's gross margin increased as the local seed price increased (as depicted in Figure 4.11) due to seed shortages. This reduced the net income loss of seed traders visualised in Figure 4.9.

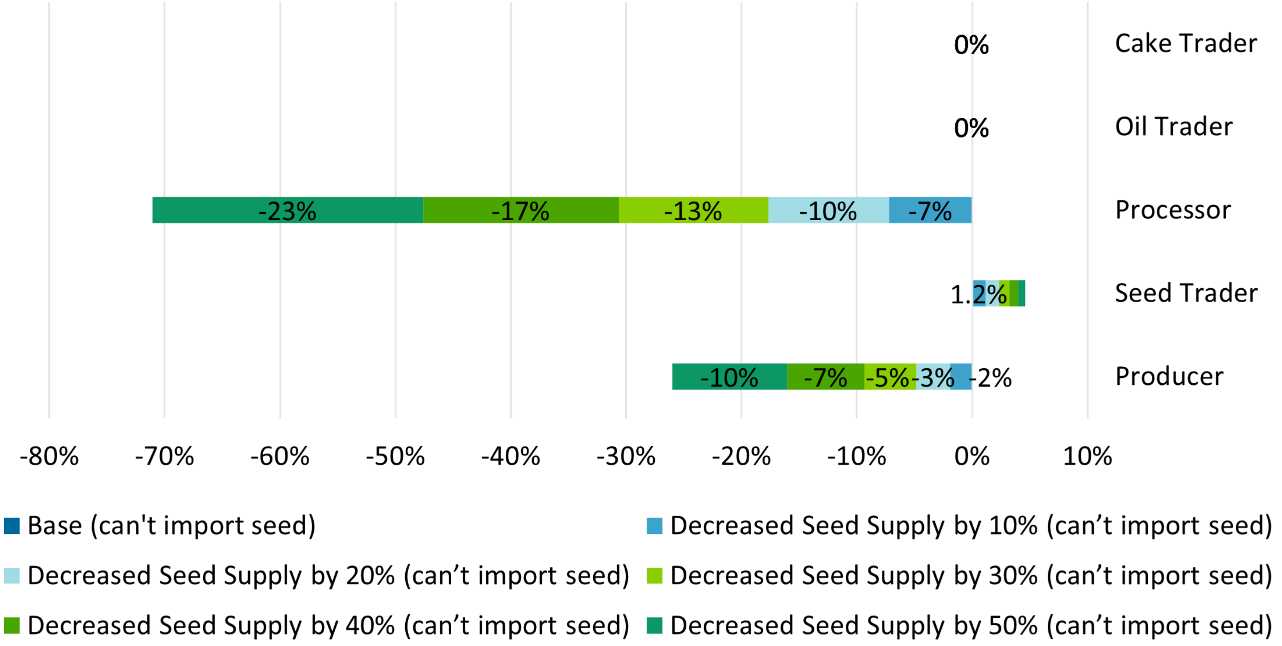

Figure 4.10: Decreased Local Seed Supply Gross Margin Percentage Change

The oil and cake traders experience the volume change on the net income level (and not on the gross margin level), because the oil and cake prices remain the same because they are not linked to local volume (only dependent on world prices). The oil and cake traders' net income decreased because the locally produced oil and cake volume declined as production decreased with the processed seed decrease illustrated in Figure 4.11 (illustrating the total seed sales decrease over the entire ten years). For this reason, the product traders' net income decreases at a higher rate (14% for 10% decrease), while the gross margin remains constant.

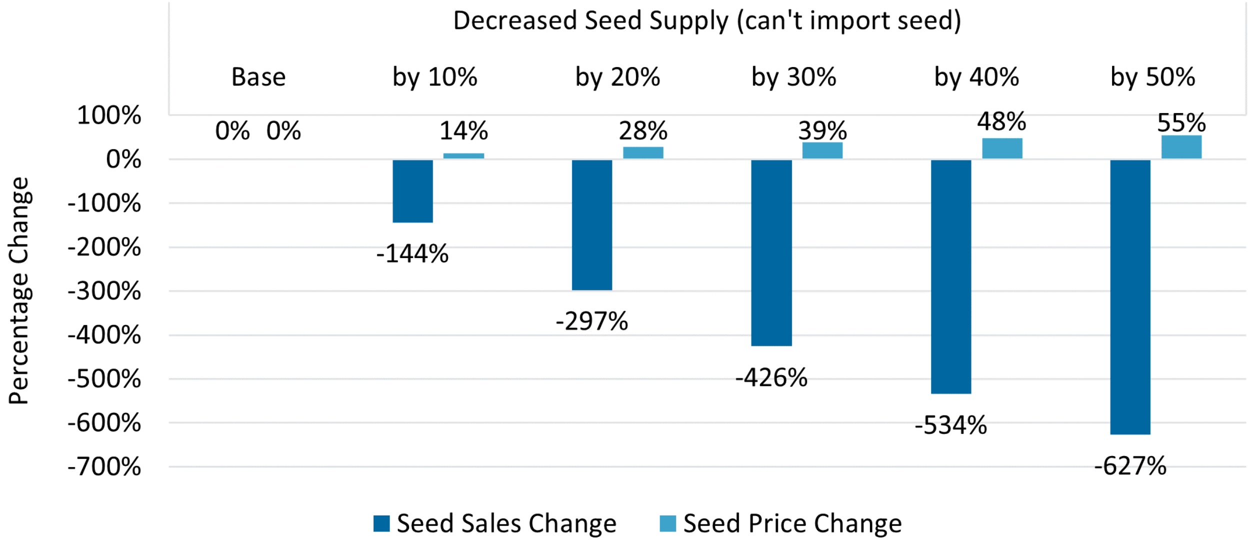

Figure 4.11: Total Change in Seed Price and Sales over the Simulated Ten Years

The results of the simulation model were used to determine the percentage that the seed producer yield would have to decrease, for the entire value chain net income to become negative. It was found that if the usually expected sunflower yield decreased by 64.4%, the value chain total net income would break even and turn negative. However, the processing node already turns negative at 55.5% of the usual sunflower yield level.

Correlation between Seed Availability and Profitability per Node

Figure 4.12 illustrates the correlation between the volume of seed produced and the gross margin per ton, as well as the correlation between the volume of seed produced and the total net income of each node in the Tanzanian sunflower value chain. Because net income is calculated by multiplying gross margin by volumes, the correlation between volumes of seed produced and net income are all close to 100%. Thus, it may be more relevant to look at the correlation between seed availability and gross margin per node, as it excludes the direct volume impact and focuses on the indirect price and cost efficiency gain and dynamic impact.

The producer gross margin correlates 92.2% with seed volume changes. Thus, if the produced seed fluctuates, the producer gross margin changes by 92.2% with the seed change. The 92.2% correlation (and not 100%) between seed volume and producer gross margin is due to the declining price and the overhead cost efficiency losses.

The same applies to processors, which correlate by 95%, thus even more aligned with seed producer volumes, hence the larger percentage change in Figure 4.9.

The correlation between seed availability and seed trader gross margin per ton is negative because as the volumes decrease, the seed price increases, increasing the gross margin per ton. The volume and gross margin correlation for product traders is zero, as their margin is simply a markup on their purchase price.

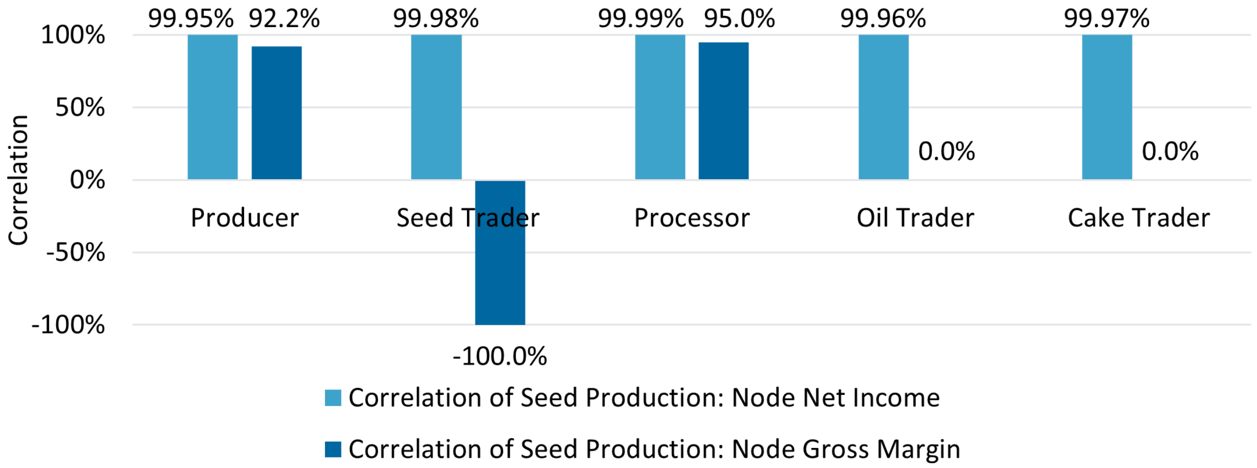

Figure 4.12: Correlation Between Seed Availability and Gross Margin and Net Income per Node

From the decreased seed supply scenario results, the impact that limited seed availability has on the entire value chain financial sustainability and each specific node can be quantified in absolute US dollar terms, as well as the percentage change. This assists the industry in defining the value that can be invested in contingency plans (like new hybrid seed technology) to prevent the local seed supply from decreasing as modelled. Thus, assuming a 10% yield loss, a maximum of 196 million US dollars can be invested to prevent a 10% yield loss. Furthermore, the model identified the break-even point for the value chain to become financially unsustainable (when the total value chain net income becomes negative), which can assist in risk mitigation to manage the value chain and avoid the scenario.

The results show that the impact is not a direct one-to-one relationship, but rather a combination of factors that try to react due to the lack of available raw material.

4.3.3 Scenario 2: Increased Local Seed Supply

To evaluate the impact of increasing the available raw material, the yield was increased in increments of 10%, from 10% to 50%. The total value chain net income gain over the entire ten years ranged from 764 million US dollars for a 10% increase in seed supply, to approximately 3 billion US dollars for a 50% seed increase.

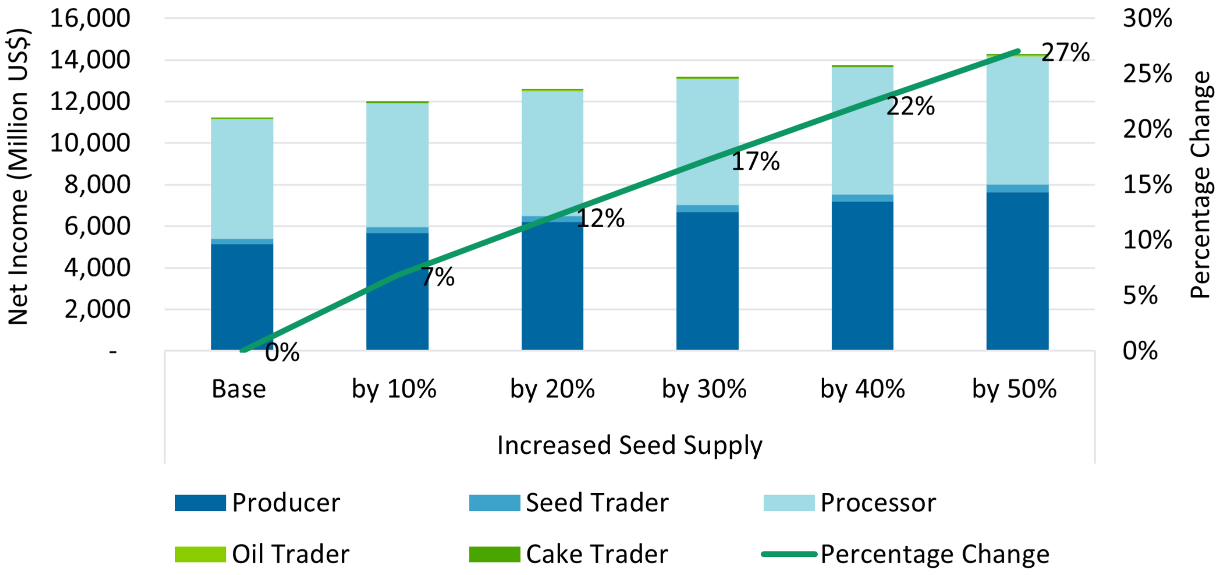

Figure 4.13: Increased Local Seed Supply Net Income Effect

The percentage increase of the total net income is lower than the increase in volume (for each scenario adding 10%), because of the volume, price and cost dynamics. The percentage change of the total value chain net income slows down as the available seed increases (the difference between the net income percentage change of 10% and 20% is 5.3%, while the difference between 40% and 50% is 4.8%). This is due to producers and processors reaching their maximum utilisation and capacities, and not realising any further efficiency gains. Furthermore, the increase in local seed supply decreased the seed price (the total percentage change across the ten years of the local seed price is illustrated in Figure 4.14) as more volumes were available, driving down the price.

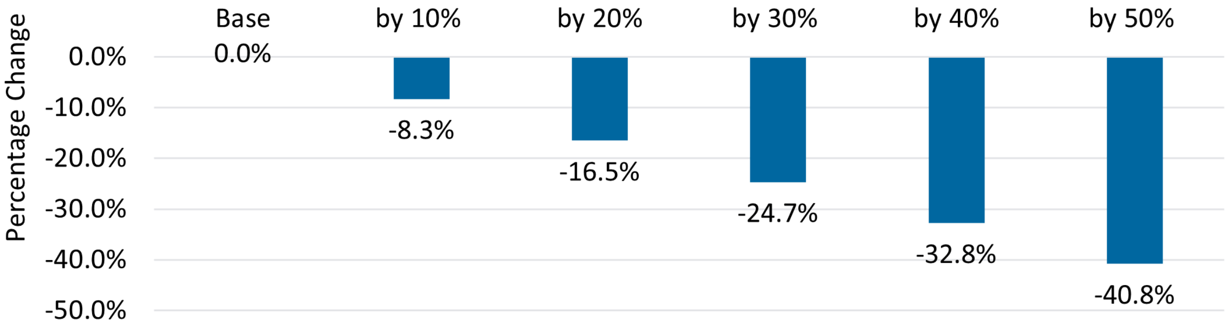

Figure 4.14: Change in Seed Price due to an Increase in Local Seed Supply

The decrease in the local seed price has a negative impact on the producer's gross margin, however, the increase in volume provides producers with the opportunity to split their overhead costs between more produced seed volumes (while variable costs increase with the increased seed production), decreasing the total cost of seed production due to efficiency gains. The increase in volumes produced, plus the efficiency gain of lower production costs, minus the loss due to lower seed prices, results in a trade-off and producers obtaining a 2% higher gross margin (illustrated in Figure 4.15) and gaining 10.4% more net income under the 10% increased seed scenario as illustrated in Figure 4.16.

The decrease of the seed price (due to volume increase) decreased the seed trader's gross margin by 0.7% (depicted in 4.15). This decreased the seed trader net income such that instead of having a 10% increase due to the 10% increase in volumes traded, seed traders only experienced a 7.5% net income increase. This effect could easily have been missed if the analysis had not been conducted with a system dynamic model that ensures that all feedback loops are taken into account.

The processor's gross margin and net income increased by 3.7% due to the trade-off between volume increase and decrease in seed price. The small increase is due to the fact that the oil and cake prices remained constant because no changes occurred for the global prices, and due to the fact that processors still produced the same amount of products and processed the same amount of seed (their maximum capacity) which resulted in no productivity gains, as they already processed at maximum capacity as discussed in the base model in Section 4.3.1. Processors reaching their maximum capacity had a ripple effect on the rest of the value chain, as the net income percentage increase for producers and traders slowed down for yield level increases above 20%.

As with the decrease in local seed availability (discussed in Section 4.3.2), the oil and cake traders' gross margin remained constant (as prices and costs are not influenced by the seed volume change), and the net income also remained constant as the processors maximum capacity had been reached and no additional volumes were produced and traded.

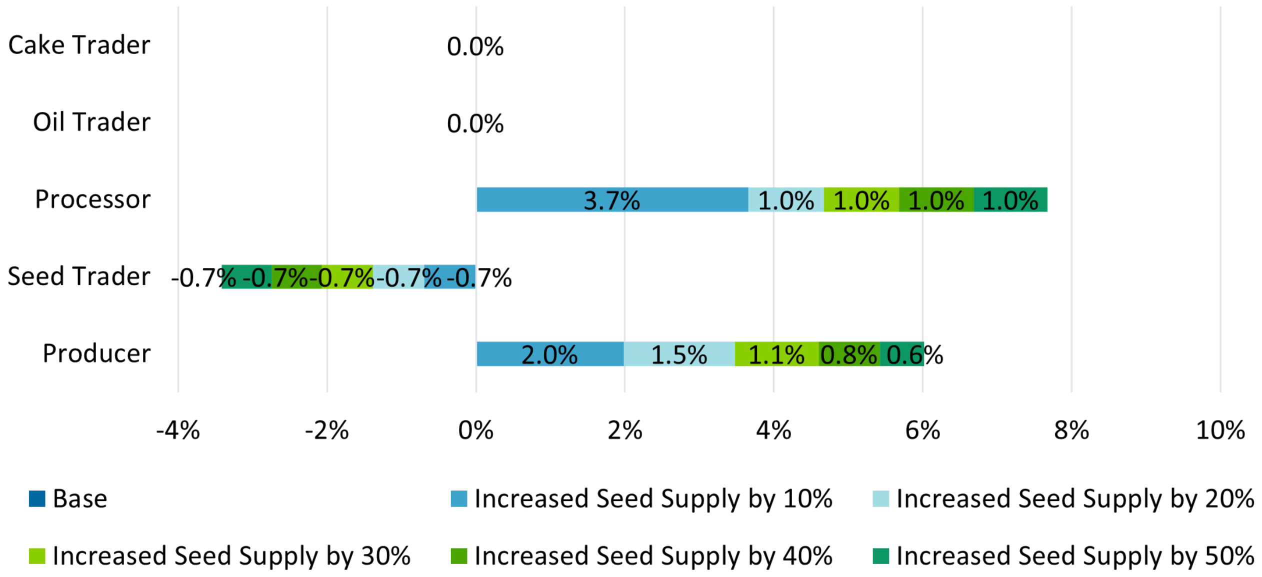

Figure 4.15: Increased Local Seed Supply Gross Margin Percentage Change

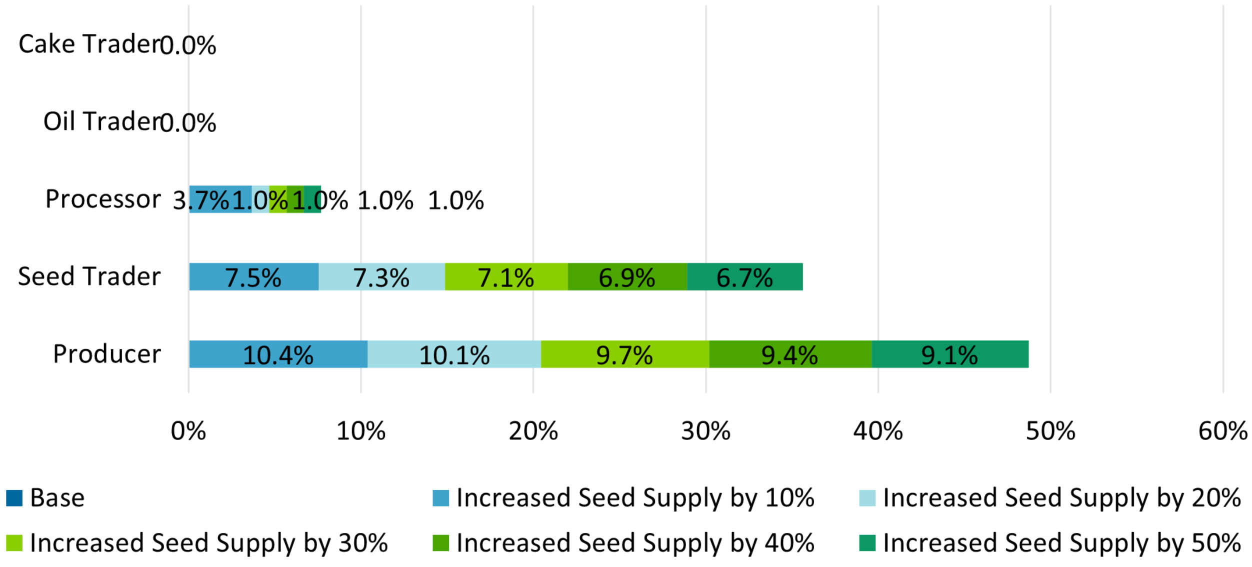

Figure 4.16: Increased Local Seed Supply Net Income Percentage Change

Overall, the 10% increase in yield added an average of 76 million US dollars (7% increase) per year to the sunflower value chain net income. While a 50% yield increase increased the total value chain net income by 304 million US dollars per year (27%). The results indicate how an increase in seed production outperforms the price decrease. However, a loss is still observed due to the price decrease which reduces the positive impact.

Furthermore, the value chain is unable to capitalise on the increase in seed volumes throughout the value chain because of insufficient processing capacity. This emphasises the importance of investing in all nodes of the value chain in order to uplift the value chain to an improved state.

4.3.4 Scenario 3: Source Comparison

Sunflower processors in Tanzania can buy sunflower seeds from two different sources, namely locally produced sunflowers and sunflowers from other countries (imported sunflowers). Seed imports are especially important if the country does not produce sufficient local raw materials, possibly making it more feasible for processors to procure and ensure the continuation of processing with increased utilisation. Figure 4.17 compares the total value chain net income over the ten years when seeds are not imported (”Base Without Import” as in Scenario 1), to when seeds are imported (”Base Import”). The data labels in Figure 4.17 sdillustrate the net income percentage change between the two scenarios (”Base Import” to ”Base Without Import”) for each node.

Overall, the total value chain net income is 7% higher when seed is imported than when seed is not imported, due to a higher volume of seed moving through the entire value chain.

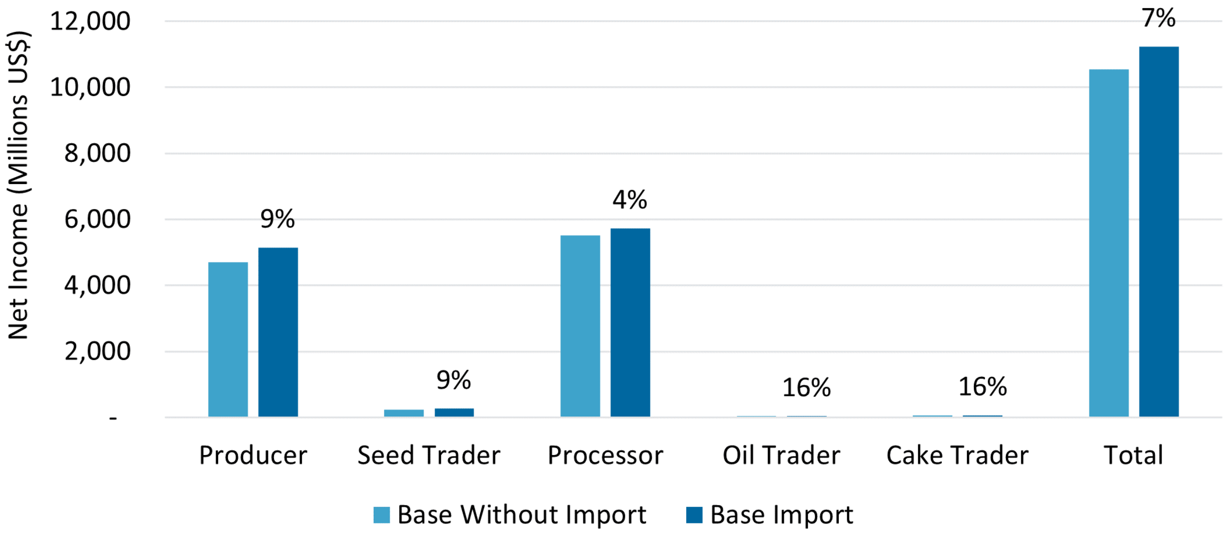

Figure 4.17: Source Comparison Net Income Effect

In the scenario simulation where seed can be imported, the net income of seed producers is higher than in the simulation where seed cannot be imported (”without import”) because more seed is produced. When importing seed, the local seed production increased due to a larger area under production as the area is dependent on seed sales (which includes seed imports, and thus increased). Thus, instead of decreasing the processed seed, processors import additional required volumes of seed, which in turn increases the local seed production area.

Due to the increase in seed production (due to an increase in area, while yield remains constant), the local seed price is lower when the seed can be imported, decreasing the seed producer’s gross margin (while the imported seed remains more expensive than local seed). Thus, the producer net income is negatively influenced by the lower gross margin but offset by the higher volumes of seed produced due to the area increase (which has a 12-month delay as the seed is only produced and harvested once a year). The producer’s net income is 9% higher if seed is imported.

The processor node purchases the imported seed to ensure continuous processing. By purchasing imported seed, processor utilisation increases by 13%. Due to the higher price of imported seed, the processor’s gross margin decreases and net income does not increase with the utilisation increase (13%) but rather increases by 4% as illustrated in Figure 4.17.

The seed traders’ net income is higher when seeds are imported because more seeds are locally produced (due to the increase in seed sales) and traded. However, the local seed price is lower (due to more available seeds), decreasing the seed trader’s gross margin and net income (because their gross margin is highly dependent on the local seed price, as they add a percentage margin to the local seed price for trading). Because there is more oil and cake produced under the scenario where seeds are imported, oil and cake traders make a 16% higher net income.

Figure 4.18 illustrates the change in total net income at different yield levels when seed is imported and when seed is not imported. At the 10% lower seed supply, the without-seed import scenarios are close to the same level as the with-seed import scenarios with a 10% lower seed supply (import with 20% decreased seed supply).

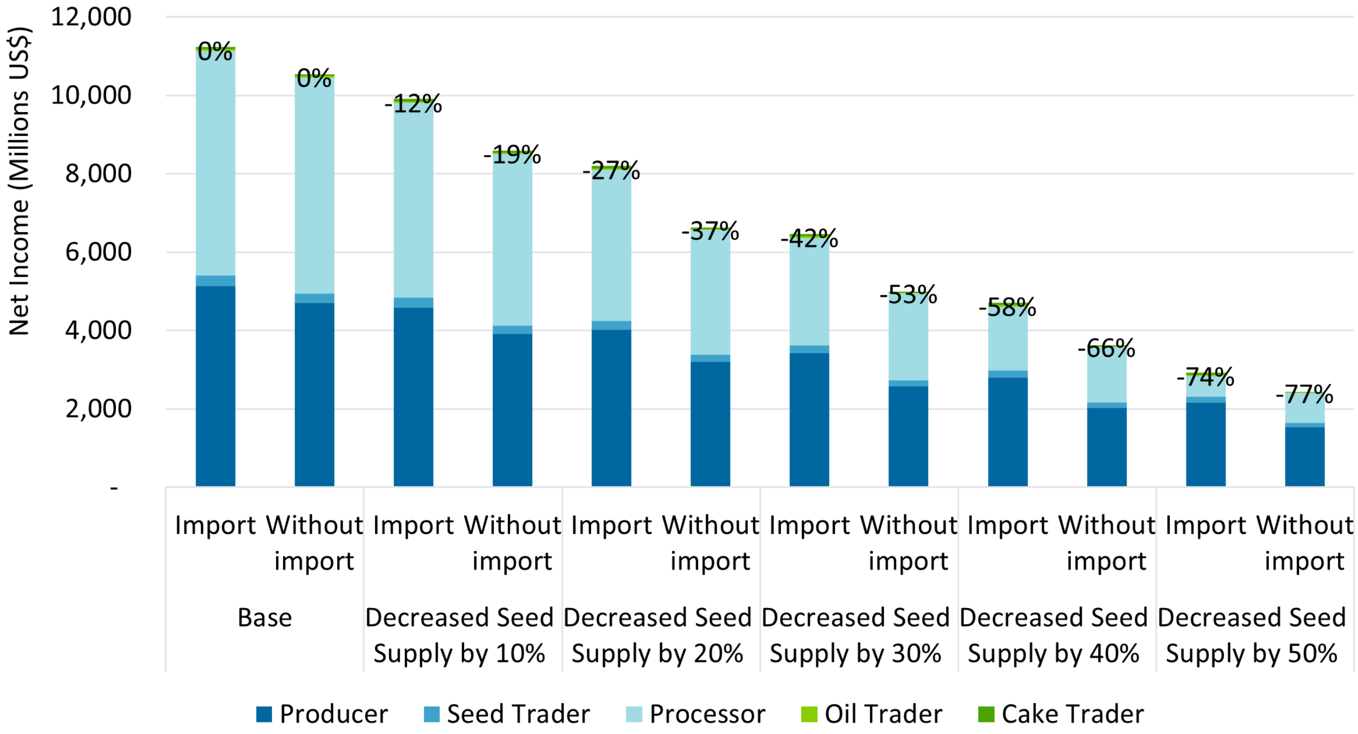

Figure 4.18: Source Comparison of Net Income at Different Seed Availability Levels

The analysis illustrates that importing the lacking volumes of seed may be beneficial for the entire value chain. The total change in net income for the entire value chain at the current base state is 7% from without-import to with-import. This amounts to roughly 68 million US dollars per year in additional net income for the entire value chain if seed is imported. The effect is mainly driven by an expansion in the sunflower-producing area due to higher seed purchases. The results are unconventional, as they suggest that it may be beneficial to temporarily import raw materials to kick-start the local industry. However, this should be investigated further by analysing the local versus imported price dynamics and possible indirect impacts, to ensure that the imported seeds do not flood the market and make local production uncompetitive.

4.3.5 Comparison Between Scenario 1, Scenario 2 and Scenario 3

Figure 4.19 compares the three scenarios discussed in Sections 4.3.2 to 4.3.4. The figure depicts the total net income of the base model (importing and not importing seed highlighted in red) with the total net income at different limited seed volumes of Scenario 1 (not importing seed), the increased seed Scenario 2 (importing seed) and decreasing local seed availability levels while importing seed (Scenario 3).

The "Base Without import" scenario decreases the total net income by 6%, as lower volumes move through the value chain reducing the net income. Thus importing seed to mitigate limited local seed supply increases the total value chain net income from 10.5 billion US dollars to 11.2 billion US dollars over the entire ten-year period. The net income increase is almost at the same level (7%) as is obtained if 10% additional seed volumes are available.

The percentage change in total net income is depicted on top of the bars, calculated as the difference between the different scenarios and the base models (highlighted in red). The increased seed supply simulations (to the left of the red bars) are compared to the base model where seed is imported, while the decreased seed supply scenarios (to the right of the red bars) are compared to the "Import" or "Without import" base simulation depending on the scenario.

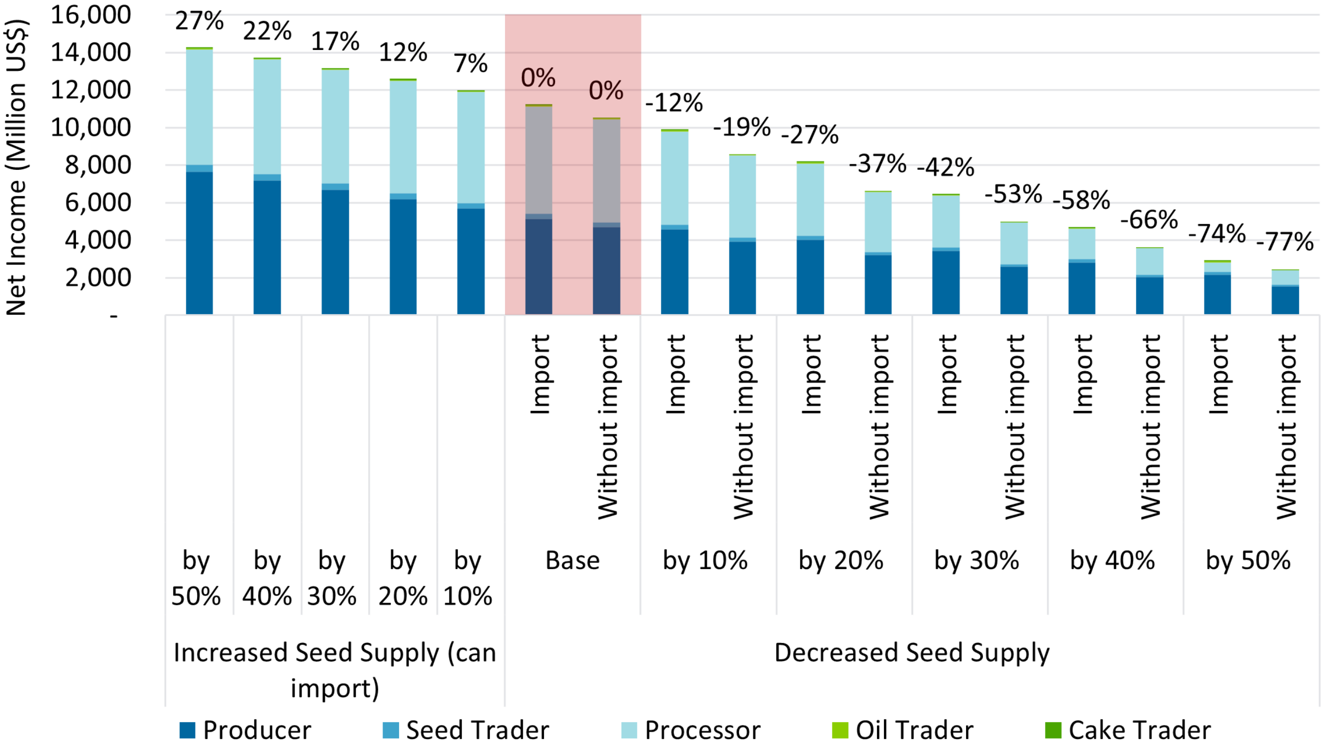

Figure 4.19: Scenario 1, Scenario 2 and Scenario 3 Net Income Comparison

The results illustrate that a negative lower seed availability level (Scenario 1), has a bigger impact than a positive higher seed availability level (Scenario 2). A decrease of 20% in seed availability decreases the total value chain net income by 27% if seed is imported. While a 20% increase in volume availability increases the total value chain net income by only 12% (compared to the base model that allows imports), which is the same as the negative impact of a 10% seed volume decrease. The low 12% increase is because local processors cannot absorb the total 20% seed increase, and consequently do not realise the full 20% net income gain.

The scenarios highlight that if seed production increases significantly, processors should expand and invest in more capacity to absorb the additional seed. The large difference between the decrease and increase in seed production highlights the importance of managing seed availability.

4.3.6 Scenario 4: Value Chain Processor Volume Optimisation

Given the trade-offs of different seed availability levels and sources, and the impact on the entire value chain, as discussed in Section 4.3.5, it is beneficial to determine the ideal amount of seed to be procured. The optimisation scenario assists in understanding under what circumstances the value chain will perform at its best, given the trade-off between higher costs for imported seed and lower overhead costs at a higher utilisation rate. The model considers all dynamics of the system and ensures that no indirect influence is missed when trying to develop an ideal state for the value chain. It is important to note that the results are unique to the 2022 global oilseed situation where oil prices sky-rocketed due to the Covid-19 pandemic and the Russia-Ukraine war.

Maximising the Total Value Chain Net Income

The simulated optimisation model concluded that the ideal amount of seed to be processed in 2022 is 45,998 tons per month. This is below the processing capacity of 204,116 tons per month, and lower than the current seed sales of 67,833 tons per month (BFAP, 2022). The results of the optimisation model were inserted into the base Tanzanian sunflower value chain model to calculate the total net income per node for the ideal state. Figure 4.20 compares the optimisation experiment's ideal solution to the base model, which represents the actual current state in 2022 and projects ten years into the future as discussed in Section 4.2.1.

Under the optimisation scenario ("Ideal Value Chain Model" in Figure 4.20), all nodes experience an improvement with an increase in total net income, except for the oil and cake traders which have a lower net income due to the reduced volumes that can be traded as less seed is being processed. Given the ideal scenario, the seed trader would experience the highest increase of 22%, producers 19% and processors 6%. If processors purchase 45,998 tons per month, the entire value chain would earn 1.42 billion US dollars (13%) more over the entire ten-year period.

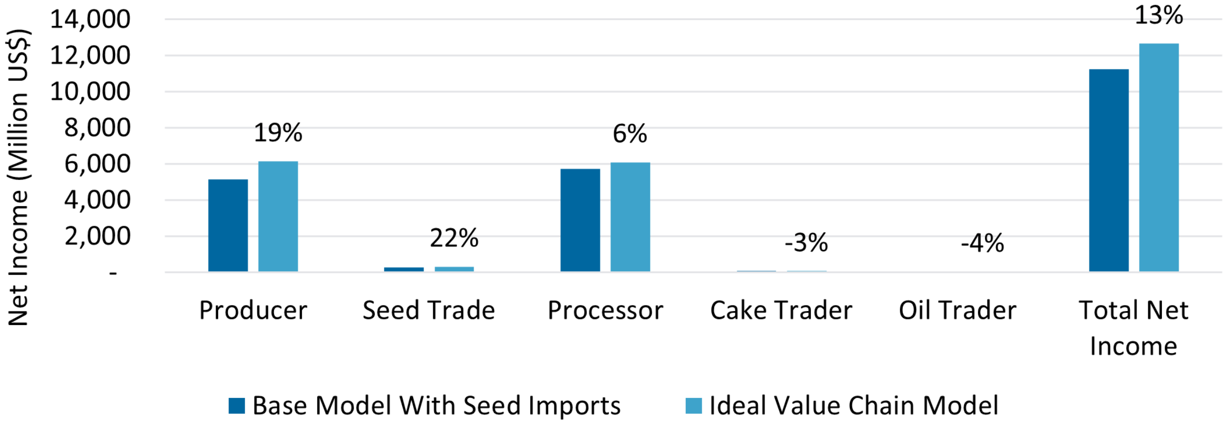

Figure 4.20: Net Income per Value Chain Node for the Base Model versus the Ideal Value Chain Model

The producer node would gain 19% in net income due to a 28% increase in seed production over the entire period as illustrated in Figure 4.21. Initially and at the end of the ten-year period, less seed would be processed under the optimisation scenario than the base model as the processor profitability is undesirable (due to high seed prices and slightly lower product prices), reducing the seed purchases and processing.

By keeping the volumes processed in 2022 low, the results clearly show that imported seed is too expensive to offset the efficiency gains obtained due to a higher processing utilisation. The ideal seed to be processed is not even the maximum amount of seed available from local seed production. This clearly illustrates that in 2022 the trade-off between the cost to process is too high to offset volume efficiency gains.

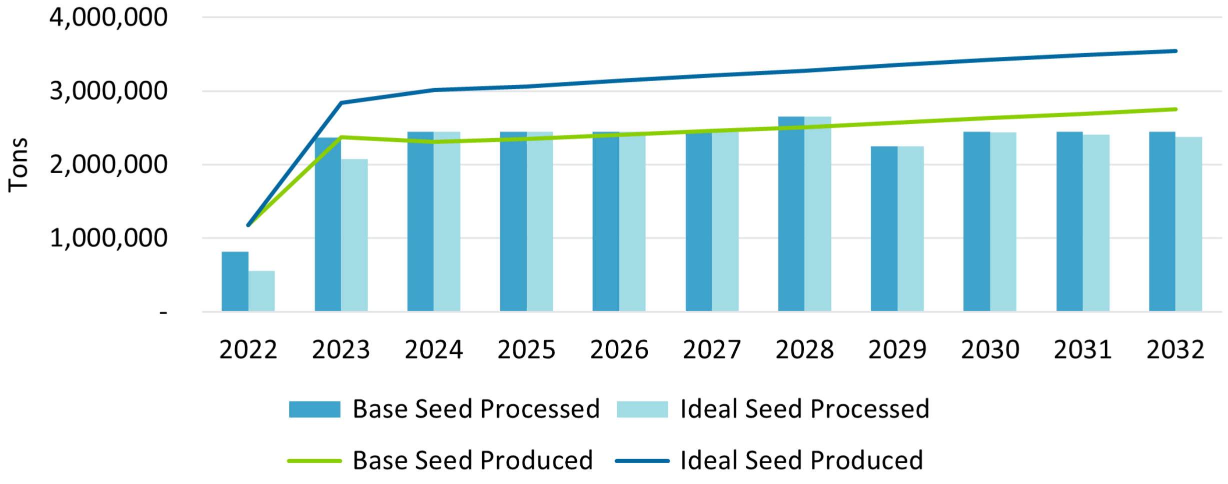

Figure 4.21: Seed Production and Processing Volumes of the Base Model versus Ideal Value Chain Scenario

Given the fact that an increase in processing volumes decreases overhead costs, one would think that the best possible solution would be to process all the locally produced seeds. However, because the processor's net income in 2022 is negative (due to the high seed prices and slightly lower product prices), it makes sense to not buy all locally available seed, as this would make the processor's net income even more unprofitable. According to the optimisation model, it is beneficial for processors to wait until the seed price has dropped or the product prices have increased, before purchasing more seeds.

Despite the high seed cost, the results indicate that it is also not financially feasible to stop processing during a time of abnormally high raw material prices. This can largely be attributed to the fact that future seed processing is dependent on previous processing volumes (as developed in the model formulation, Section 3.3.2). Thus, if the volume of seed processed in 2022 was zero, processors would have to restart purchasing and the model would only be able to gradually increase future processing volumes from zero. This would impact processors negatively, as they would miss the opportunity to make higher profit margins in the upcoming years.

Thus, the ideal solution concludes that it would be financially wise for processors to process some seed in 2022 (at a loss), but then be able to ramp up production quicker to process at full capacity in the upcoming profitable years. This may be supported by operational functionality that deems it unpractical to completely stop processing, as continuous processing is good for the upkeep and maintenance of a processing plant. Furthermore, established and nourished relationships with suppliers and off-takers could be ruined if no processing occurred for an entire year, potentially leaving the processor ready to process at a profit in the following year, but without a market or seed supply.

Given these results, interventions can be developed and suggested like policies for investing in research and development for yield improvement to increase value chain financial sustainability as seen in Section 4.3.3, or decreasing processing cost by improving country infrastructure like roads and electricity supply. It is clear that any disconnect between sunflower seed prices and oil and cake prices (as seen in 2022 with high seed prices but slightly lower product prices) can have detrimental impacts on the value chain, and efforts should be taken to try and ensure that the market is not distorted (as in 2022), creating the disconnect.

Relating the Ideal Scenario to the Source Comparison Scenario

Figure 4.22 relates the optimisation results of Scenario 4 ("Ideal Value Chain Model" in Figure 4.22) to the source comparison results of Scenario 3 ("Base Model With Seed Imports" and "Base Model Without Seed Imports" in Figure 4.22), and illustrates that importing seed is better than not importing seed (increasing the total value chain net income by 7%), if processors have to maintain their 2022 utilisation (process 67,833 tons per month). But to maximise the entire value chain net income, the optimisation model depicts that seed should not be imported and fewer volumes should be processed in 2022 (45,998 tons per month). In the following years, processing volumes can be increased again, once processor profitability has improved. This will increase the total value chain net income by another 6%.

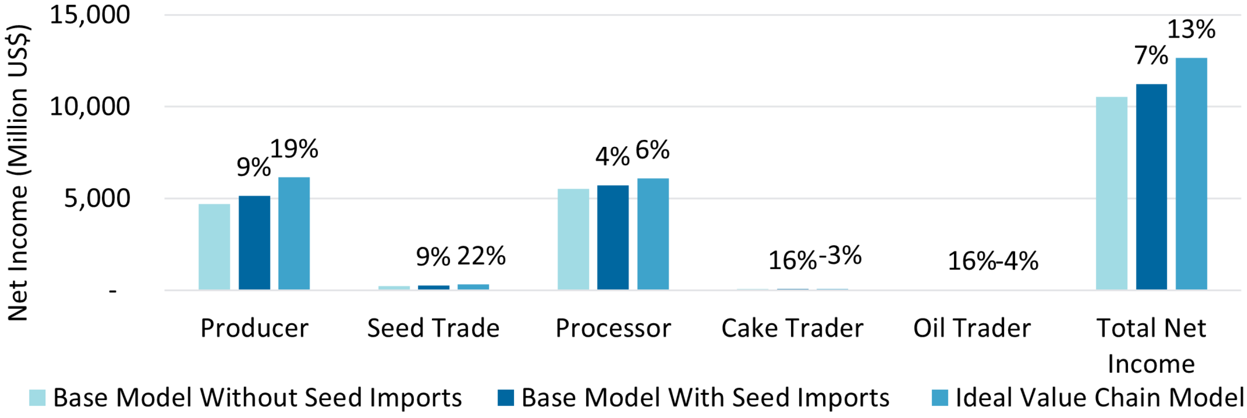

Figure 4.22: Net Income per Value Chain Node for the Ideal Value Chain versus Base Model With Seed Imports versus Base Model Without Seed Imports

Maximising the Seed Processor Net Income

When maximising the net income of the processing node, the ideal amount of seed processed in 2022 is 47,138 tons per month. This is higher than when maximising the total value chain net income (45,998 tons). Figure 4.23 compares the net income of each node in the base model (not optimised) to the ideal value chain model and the ideal processor model. Processors would increase their net income by 0.1%, while producers would lose 1.1%, and seed traders 1.3% of their net income (compared to the ideal of the value chain). The loss in net income for producers and traders is due to the loss in volumes. With the decrease in seed volumes, the price increases, but it does not replace the revenue loss due to the volume decrease. The total value chain would have earned 53 million US dollars less over the entire ten years, and both the producer and seed trader nodes would operate at a sub-optimum if the processor net income was maximised instead of the entire value chain net income being maximised. However, the processor and product trader nodes would operate at an ideal level.

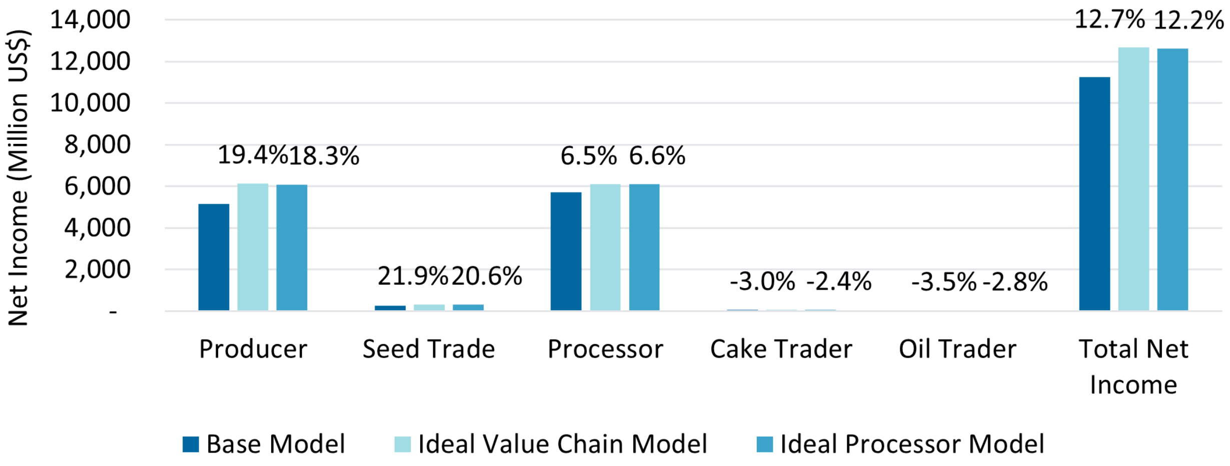

Figure 4.23: Net Income per Value Chain Node for the Base Model versus the Ideal Value Chain versus Ideal Processor Scenario

Relating the Value Chain and Seed Processor Optimisation Results

Overall, the results illustrate that for the current Tanzanian sunflower value chain with the current installed processing capacity, less than the installed processing capacity should be processed in 2022 (during the year with the high seed price) to maximise the value chain and processor net income. After 2022, the volumes of seed processed can be increased, while continuously taking into account the trade-off between seed price and cost efficiency gains obtained due to higher processing volumes (as illustrated in Figure 4.21).

These results are insightful, as they indicate that the value chain would not perform at its ideal value chain financial sustainability by processing more volumes, and that increasing the local seed production will not solve the problem on its own. The results suggest, that besides an increase in local seed production, processor-specific interventions (like an investment into further processing capacity) should also be considered to uplift the entire value chain. This emphasises the importance of taking the entire value chain into account when trying to improve the total sunflower industry, and refrain from changing one aspect in isolation (like increasing seed availability). The developed system dynamic model can assist in determining the required combination of interventions, by simulating different scenarios, analysing the impact on the entire sunflower value chain and running different optimisation experiments at different seed production and processing capacity levels.

It is encouraging to see that the ideal seed processed for maximising the entire value chain and for maximising the processor node net income is similar, as this indicates that the processor's objective aligns with the entire value chain's objective. Hence, similar interventions will promote the entire value chain and are unlikely to negatively influence the processor when the rest of the value chain is uplifted, and vice versa. The fact that the ideal solution for both optimisation scenarios is similar, suggests that uplifting the processor should have a positive impact on the rest of the value chain. The results suggest that there is no disconnect between the processor's financial sustainability and the rest of the value chain.

4.4 Model Analysis Conclusion

Given the model's accurate simulation of the Tanzanian sunflower value chain, it could be concluded that the model accurately represented the real system, providing reliability and accuracy to the results. The results were also compared to the expected results generated in the background and problem environment (Section 3.1.1). The results illustrated that the developed model is capable of analysing and quantifying the impact of different processor seed availability levels on the entire value chain financial sustainability, by running and analysing different scenarios with different seed production volumes and seed sources. The simulated scenarios produced interesting results that may have been overseen without the system dynamic model.

The results of the limited seed availability scenario (Scenario 1) indicated that the total value chain net income would be more severely impacted than the volume loss (where a 10% decrease in seed volume decreases the total value chain net income by 19%), and highlights that the impact is not a direct one-to-one relationship, but rather a combination of factors that react according to the lack of available raw material. The increase in seed price due to a drop in seed availability, is insufficient to prevent the net income decrease due to volume and consequent efficiency losses. The model quantifies the impact of different limited raw material processor availability levels, quantifying the impact of the processor's financial sustainability on the entire value chain. The node with the largest loss is the processing node due to a combination of factors (price, cost efficiency and volume). The model also assists in defining the amount that can be invested in developing contingency plans for prevention and management. Furthermore, the model identified the break-even point for the value chain to become financially unsustainable (if the usually expected sunflower yield decreases by 64.4%, the value chain total net income will break even and turn negative), which can assist in risk mitigation to manage the value chain and avoid the situation.

On the other hand, an increase in local seed production (Scenario 2) will give the seed production node the highest reward (mainly driven by the volume increase) while processors are expected to only increase their net income by a fifth of the volume increase, as they hit their capacity ceiling preventing further overhead cost savings. Overall, the total value chain is expected to gain less than the volume increase (only a 7% increase for a 10% increase in seed produced), partly due to the price drop as the seed volume increases, but mainly due to the utilisation reaching the maximum efficiency gain. The results indicate that an increase in seed production outperforms the gross margin loss, and highlight that if seed production increases significantly, processors should consider expanding and investing in more capacity to absorb the additional seed, process locally and supply the local market. The large difference between the decrease and increase in seed production highlights the importance of managing seed availability and processing capacity (to prevent efficiency gain losses due to processing capacity reaching their maximum ceiling).

The source comparison scenario indicated the value of a system dynamic model by quantifying the indirect positive impact of being able to import seed on the entire value chain, providing processors with the opportunity to continue processing, and increasing the seed demand. The advantage of importing seed (7% at the base model level without a limited seed simulation) is almost at the same level as having 10% additional seed available for processing, which also adds 6% net income. However, the results are unconventional, as they suggest that it may be beneficial to temporarily import raw materials to kick-start the local industry. Before promoting seed imports, the situation should be further investigated to ensure that the local sunflower seed production is not impacted negatively due to imported seed.

The optimisation experiment identified the ideal amount of seed to be processed to maximise the total value chain net income, given the trade-off between seed price and volume. The results indicate, that given the current value chain state (which is unique, given the current high oil prices due to the Covid-19 pandemic and the Russia-Ukraine war), increasing the seed processing volume at a higher price is not beneficial. The ideal amount of seed to be processed for maximum total value chain net income in 2022 was determined as 45,998 tons per month (which is below the current seed processing volumes), increasing the net income of all nodes except for the oil and cake trader nodes (as fewer volumes flow through the noes). While to maximise the processor's net income, slightly more 47,138 tons per month should be processed.

The results illustrate that uplifting the processor's financial sustainability would improve the overall value chain sustainability and that the processor's objective is relatively aligned with the value chain objective. This makes intervention development easier as an intervention that targets processors should positively influence the entire value chain.

However, given that the ideal seed processed is below the current processing volumes, the results indicate that the value chain would not perform at its ideal value chain financial sustainability by processing more volumes, and that increasing the local seed production will not solve the problem on its own. This emphasises the importance of a combination of interventions representing the entire value chain and refraining from changing one aspect (like increasing seed availability) in isolation. The developed system dynamic model can assist in determining the required combination of interventions, by simulating different scenarios and optimisation experiments, and analysing the impact on the entire sunflower value chain.

The discussed scenarios illustrated that the developed model is capable of analysing and quantifying the impact of different interventions like introducing high-yielding seed varieties that increase sunflower production and allowing seed imports. A variety of further scenarios can be run and analysed, as discussed in Chapter 5

Conclusion

This project aimed to measure and analyse the impact that fluctuating seed supply has on the Tanzanian sunflower value chain's financial sustainability. The main objectives were to illustrate the interconnectivity of the value chain, understand the effects and impact that the varying seed availability of one node (the processing node) can have on the entire value chain's financial sustainability, and determine the ideal seed sourcing volume to maximise value chain net income.

The literature review concluded that there are many different approaches to analysing impacts on a value chain, but there seems to be a gap in the literature on representing the entire value chain in a model that incorporates the dynamics and effects of the value chain and its nodes. Literature around treating a value chain as a complex adaptive system was further researched, from which system dynamics was identified as the most appropriate technique for the problem. System dynamics has been used in literature to analyse value chain behaviour for different scenarios and is often used to assist in decision-making. Furthermore, system dynamic applications have combined dynamic engineering representations with accounting models to economically optimise the system.

Different financial sustainability indicators were reviewed in the literature, where net income was identified as the main value chain sustainability and performance indicator. Net income was selected due to its wide application and simple way of illustrating the performance of a value chain and its nodes.

Executed Approach and Results

The proposed approach identified from the literature was developed and executed for the Tanzanian sunflower value chain by analysing the problem and background, developing the dynamic hypothesis and causal loop diagram, formulating the mathematical equations and the stock-flow diagram and developing the model in AnyLogic before validating and verifying the model. All the steps were executed in an iterative approach to develop a system dynamic model that represented the Tanzanian sunflower value chain (producers, seed traders, processors, oil traders and cake traders nodes) from 2012 to 2022. After establishing that the model represented the historical reality and simulated the industry under extreme conditions, the model was adjusted to project the next ten years (2022 to 2032) of the Tanzanian sunflower value chain, on which the scenarios were imposed and analysed. The future ten years were analysed because nothing can be done to change the past, but analysing different scenarios can assist in planning for the future.

The scenarios of decreased and increased seed availability, source comparison and volume optimisation were executed, analysed and discussed. The scenarios quantified the impact of a change in available processor seed volumes on the entire value chain, as well as each specific node. A decrease in seed availability yielded a larger impact on the total value chain net income than the imposed seed volume percentage decrease. While an increase in volume yielded a smaller impact than the volume increase due to the price drop resulting from the seed volume increase, as well as processor cost efficiency gains having achieved their maximum as the processing capacity is reached.

Quantifying the impact assists the industry in comparing the cost and losses of different limited raw material availability levels and assists in developing contingency plans for prevention and management. Thus quantifying how much is lost, informs how much can be spent to prevent the loss while not going beyond what could potentially be lost. The results of the simulation model were used to determine the percentage that the seed producer yield would have to decrease, for the entire value chain net income to become negative. It was found that if the usually expected sunflower yield decreased by 64.4%, the total value chain net income would break even and turn negative. However, the processing node already turns negative at 55.5% of the usual sunflower yield level.

When analysing the scenario where seed can be imported versus where seed cannot be imported, a positive consequence of importing seed was obtained, almost in line with the positive impact of an increase in local seed supply. The results can be explained by the fact that the processor's utilisation and seed purchases increased, providing a more secure market and higher demand for seed producers, which in return increased local seed production. However, the results are unconventional, as they suggest that it may be beneficial to temporarily import raw materials to kick-start the local industry. Before promoting seed imports, the situation should be further investigated to ensure that the local sunflower seed production is not impacted negatively due to imported seed. These results illustrated the model's ability to represent structural changes and interventions on the value chain and quantify the impacts.

The optimisation scenario considered all dynamics of the system and ensured that no indirect influences were missed when trying to maximise the total value chain net income. The results indicated, that given the current value chain state (with the 2022 global oilseed situation due to the Covid-19 pandemic and Russia-Ukraine war), increasing the seed processing volume at a higher price is not beneficial for the total value chain net income. The simulated optimisation model concluded that the ideal amount of seed to be processed in 2022 is 45,998 tons per month for maximising the total value chain net income, and 47,138 tons per month to maximise processor net income. Given that the ideal solutions are so similar, the results point towards the fact that the objectives of the processor and the total value chain were aligned and further strengthened the hypothesis that a change in available processor seed volumes and the processor's financial sustainability, has a positive impact on the entire value chain sustainability. However, due to the fact that the ideal seed processing volume for 2022 was below the current processing volumes, the model illustrated that interventions should be developed for all nodes in the value chain and not only for one node in isolation.

Research Contribution

The model development with the model validation and verification, and scenario analysis illustrated that the developed system dynamic model is capable of accurately representing the historic and future Tanzanian sunflower value chain, contributing scientifically, as such a system dynamic model has not been developed before.

The model contributed by aiming to quantify the impact that a sustainable processing node can have on the entire value chain sustainability by modelling the impact of sufficient and insufficient raw material at the processing node. The results suggest that there is no disconnect between the processor's financial sustainability and the rest of the value chain. The model incorporated the impact of processor profitability due to a change in raw material availability on the entire value chain.

The developed model's results can inform decision-making to increase the sustainability of the entire Tanzanian sunflower value chain, and the financial health of all stakeholders. Furthermore, different scenarios and black swan events (like a change in seed availability) can be imposed on the model to quantify the possible financial impact on the value chain and its nodes. Quantifying the impact assists the industry in comparing the costs and losses of different limited raw material availability levels, avoiding break-even levels and can assist in developing contingency plans for prevention and management. It can also assist in setting realistic goals to work towards with the optimisation model. This can assist in decision-making for policymakers and investors to prioritise resources and quantifying financial impacts for black-swan events.

According to the author's knowledge, no system dynamic model has optimised an entire value chain financial sustainability before. This combination contributes scientifically by quantifying the best possible solution that is truly possible, given the current state of the value chain and its nodes.

The optimisation scenario assists in determining what is the best possible amount of seed to be purchased by processors to maximise value chain net income. This assists in understanding how much local seed production is required to make processors and the value chain as profitable as possible, and thus uplifting the value chain. The value chain optimisation helps to understand what is required to achieve an upgraded state of the industry. Often interventions promote volume increases, while further interventions are required to support the volume increase to be handled downstream of the value chain. Running the optimisation model and the basic system dynamic model together can assist in identifying the ideal state, interventions to achieve the ideal state, and bottlenecks that prevent the ideal state from being realised.

Research Limitations

The model development process illustrated that a wide variety of structures, feedbacks, connectivities and interlinkages can be modelled through system dynamic modelling, not bound by specific requirements. The approach's ability to incorporate positive and negative feedback loops supports infinite modelling options and does not restrict the modelling process by requiring a specific formula type. This allows for a wide variety of systems, especially complex adaptive problems, to be modelled that do not conform to usual structures. However, the model should be well structured and developed logically to avoid mismanagement of the model which can potentially yield incorrect results. Thus, the system dynamic model developer should take great care when developing the model in such a way that it is user-friendly and that accidental changes cannot ruin the results.

During model development, it was challenging to define the model boundary and ensure that no variable or factor was excluded and that the model was not overwhelmed. However, this was overcome by focusing on the actual Tanzanian sunflower value chain system structure and the research question, and analysing the gathered data.

Improvements to this project may include a range of refinements, like solidifying the variables that influence the cake price in Tanzania, to improve the accuracy of the model. The system dynamic model does not consider the decisions of nodes. For example, it does not take into consideration the fact that processors may decide not to purchase imported seed or even locally produced seed because it does not make financial sense (if they make a loss when purchasing and processing). This is a possible improvement that can be made to the model by including clear "if-statements".

It may be beneficial to further research methods to prove the model's accuracy under different scenarios, other than the conducted validation and verification approach of proving that the model is accurate compared to the historical data and under numerous extreme conditions that replicate black-swan events, proving that the model follows a logical and structural behaviour that represents the reality, proving model boundary accuracy, dimensional consistency and verifying data.

Furthermore, including a decision variable that takes into account crop competitiveness to strengthen the model's decision-making around area expansion for sunflower production compared to other crops. By conducting a proper analysis of competing crop profitability before increasing or decreasing sunflower area, would strengthen the model significantly. This was not included in the current model as it requires further in-depth research and analysis (with a lot of data gathering) of the competing crops, which also have trade-offs and dynamics that change over time.

A further limitation of the model is that it was developed for high-level analysis and is incapable of unpacking each node's operations. Including storage capacity and costs at the processing node given different levels of seed being stored, may provide further insight into the processor's operational and financial sustainability. Gradually increasing the impact of population growth instead of an annual jump may also improve the model's flow. Finally, including the net income of exporters in the total value chain financial sustainability calculation may improve the value chain financial sustainability indication. The net income of exporters was not included in this study, as the focus was on promoting the local industry and local food sufficiency. These different research focuses may improve the developed model for this report and with it the results.

Further Research

Given the extent of the model, further research may include more executed and analysed scenarios. For example, structural scenarios of adding an additional volume channel where small processors can sell sunflower cake to commercial processors. Or adding the dynamics of building additional processing capacity (taking into account the investment cost and time to build as done by Oleghe (2020)) can provide insight to investors around the return on investment for a processing plant in Tanzania, given the system dynamics. Furthermore, the return on any other investment, like storage facilities, may be studied, as well as an increase in costs (like electricity). Additionally, scenarios focusing on a shorter time frame (as the industry differs significantly at different times of the year due to the production cycles), can be run to unpack the cyclic annual dynamics.

It may be beneficial to run optimisation scenarios for all the nodes in the value chain (maximising each node's net income separately) as further research to gain insight into how the node's ideal states differ and how to manage them. As well as evaluate the best possible solution given different structural changes that may be due to policy or operational changes. Determining the ideal value chain state with the optimisation model given a different current state (that excludes the Covid-19 and Russia-Ukrain war impact) may also be beneficial to better understand the value chain trade-offs under more "normal" circumstances. Further optimisation scenarios may include running the optimisation experiment at different seed availability levels (increased or decreased local seed production and supply) to identify the required processing capacity at each level.

Furthermore, research may be conducted to expand the value chain sustainability indicator to include different types of indicators that represent other sustainability aspects like environmental and social governance.

The range of further research possible, emphasises the model's relevance, agility and scientific contribution to investigate different scenarios and topics of the Tanzanian sunflower value chain, which was successful in quantifying the impact of limited processor raw material on the entire value chain financial sustainability.

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