# EVALUATION OF GENERIC PALM OIL PRODUCTION AND THE ROLE OF ROUND TABLE ON SUSTAINBLE PALM OIL (RSPO) IN SMALL SCALE FARMERS IN GHANA

***A System Dynamics Approach***

**UNIVERSITY OF BERGEN**

**Submitted to the Department of Geography**
**in Partial Fulfilment of the Requirements for the Degree of**
**Master of Philosophy in System Dynamics**

**System Dynamics Group**
**Department of Geography**
**University of Bergen June 2023**

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# ACKNOWLEDGEMENT

My utmost gratitude goes to the University of Bergen for giving me the opportunity to study in this great institution. I am privileged to be a part of such an astute institution and the opportunity to meet great professors and researchers. The University has given me the best access to an international learning environment, and I am glad about this. I also appreciate the efforts the university makes to make international students have a pleasant stay and the friendly atmosphere the University provides for studies.

I would like to express my sincere appreciation to Dr. Birgit Kopainsky for her valuable guidance, useful reflections, and persistent encouragement throughout this project. It was a privilege. Thank you for your patience and good supervision skills. I am grateful for making me achieve this degree and I will choose you again any day.

Finally, I would like to acknowledge and deeply thank my family for their never-ending trust and support; this has only been possible because of them.
God bless you all.

# ABSTRACT

This study employs a system dynamics modeling approach to analyse the role of RSPO (Roundtable on Sustainable Palm Oil) small-scale farmers. The objective is to evaluate the impact of RSPO certification on agricultural productivity in the palm oil sector. By integrating variables such as land usage, yield potential, nutrient availability, water resources, and knowledge acquisition, the model simulates the dynamics of palm oil production for both RSPO and non-RSPO farmers. The model considers the unique characteristics and practices associated with each farming approach.

The findings of the study reveal that RSPO farmers consistently achieve higher yields compared to non-RSPO farmers. The RSPO certification, with its emphasis on sustainable and responsible farming practices, appears to play a crucial role in enhancing agricultural productivity. Factors such as improved land management, efficient resource utilization, and access to knowledge and technology contribute to the superior performance of RSPO farmers. The system dynamics model provides insights into the underlying mechanisms driving yield disparities between the two groups. It captures the interactions between various variables, allowing for a comprehensive analysis of the factors that influence agricultural productivity. The results of this study have significant implications for the palm oil industry and sustainability efforts. It suggests that adopting RSPO standards and practices can lead to increased yields, while promoting environmentally friendly approaches and socio-economic benefits for farmers.

In conclusion, this research demonstrates the advantages of RSPO certification in achieving higher yields in palm oil production. The system dynamics model provides valuable insights into the dynamics of agricultural systems, supporting evidence-based decision-making for sustainable palm oil cultivation and promoting the well-being of farmers and the environment.

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# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| 1. | RSPO | Round Table for Sustainable Palm Oil. |
| 2. | JOPDC | Juaben Palm oil Development Company. |
| 3. | NTFP | Non-timber Forest Product. |
| 4. | FFB | Fresh Fruit Bunches. |
| 5. | PKO | Palm Kernel Oil. |
| 6. | ECOWAS | Economic Community of West African State. |
| 7. | CPO | Crude palm oil. |
| 8. | RSSF | Smallholders Support Fund. |
| 9. | NGO's | Non-profit Organizations. |
| 10. | CLD | Causal Loop Diagram. |
| 11. | CSPO | Certified Sustainable Palm Oil. |
| 12. | TOPP | Twifo Oil Palm Plantations Limited. |
| 13. | SD | System Dynamics. |
| 14. | R1 | Reinforcing Loop 1. |
| 15. | R2 | Reinforcing Loop 2. |
| 16. | B1 | Balancing Loop 1. |
| 17. | B2 | Balancing Loop 2. |
| 18. | B3 | Balancing Loop 3. |
| 19. | B4 | Balancing Loop 4. |
| 20. | B5 | Balancing Loop 5. |

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# CHAPTER ONE

## 1.1 Introduction

Oil palm *(Elaeis guineensis)* is one of the world's most rapidly expanding equatorial cash crops, driven by increasing global demand for food (vegetable oil), industrial application and consumer products like detergents, soaps and cosmetics, as well as biofuel generation for transport and electricity due to its easy harvest, high price and high production output (Corley, 2009; Fitzherbert et al., 2008; Wich et al.2014; Van Noordwijk et al. 2017) of which the growth in its production has also contributed to improved economic growth and rural poverty alleviation. Production of palm oil on the global stage has seen tremendous growth over the last decades with Indonesia and Malaysia as the largest producers. Global production of palm oil is estimated by USDA at 50.28 million metrics tons as of September 2011 and 70 million metric tonnes as at 2018, with Indonesia and Malaysia accounting for 57% (41 million tons) and 27% (20 million tons) respectively (MASDAR report, 2011; FOA, 2018).

Ghana is widely known to be one of leading producers of palm oil with an annual production spanning around 2.4 metric tons and expansion in cultivating area of (+31,500 ha) over the past decade (FAO, 2017). Due to the multi-functional nature of palm oil, it is highly embedded in the everyday lives of both rural and urban citizens for household and industrial purposes within the Ghanaian community. As part of Government intervention to capitalise on its resourcefulness, Palm oil was selected by the Ghanaian Government as a strategic cash crop in the early 2000s to promote agricultural and industrial growth for poverty reduction and rural development of which oil palm seedlings were distributed amongst farmers', but field plantings were poorly managed (Asante, 2012; Osei-Amponsah et al. 2012; Ofosu-Budu and Srapong, 2013). In addition to government's intervention to streamline its production capacity, peasant farmers have made tremendous investment in the oil palm industry, thereby attracting interest of foreign investors to develop large-scale plantations.

Despite its revenue generating avenues, palm oil production has not been without its share of criticism. Issues surrounding palm oil production over the years concerning its environmental and social implications have uncovered legitimate questions on management practices along its production line. Research over the years has shown that producing palm oil in an unsustainable manner has negative environmental impacts which outweighs its contribution to reducing emissions as an alternative to fossil fuel generation (Fargione et al. 2003; Tilman et al. 2009).

## 1.2Reference Mode

Palm oil production in Ghana employs millions of workers, and it is considered the second most important tree crop in the Ghanaian economy after cocoa. It is therefore one of the leading cash crops in the rural economy in the forest belt of Ghana according to CSIR-Oil Palm Research Institute-Ghana. Oil palm serves as a raw material for industry and a source of foreign exchange. Production of palm oil now accounts for 37 percent of the total global output of oilseeds, overtaking soybean oil as the leading vegetable oil. Malaysia and Indonesia dominate world production and trade with 90 percent of global output, while West Africa accounts for a negligible 3.5 percent (Ofosu-Budu, K., and D. Sarpong 2013). Import of palm oil reached 119,821 Metric Tonnes with a trade value of USD 57.2million (Figure 2) whiles export for 2019 were significantly 15,392MT with trade value of USD 11.1million which is roughly about one-fifth of the import value (Awere et al, 2022).

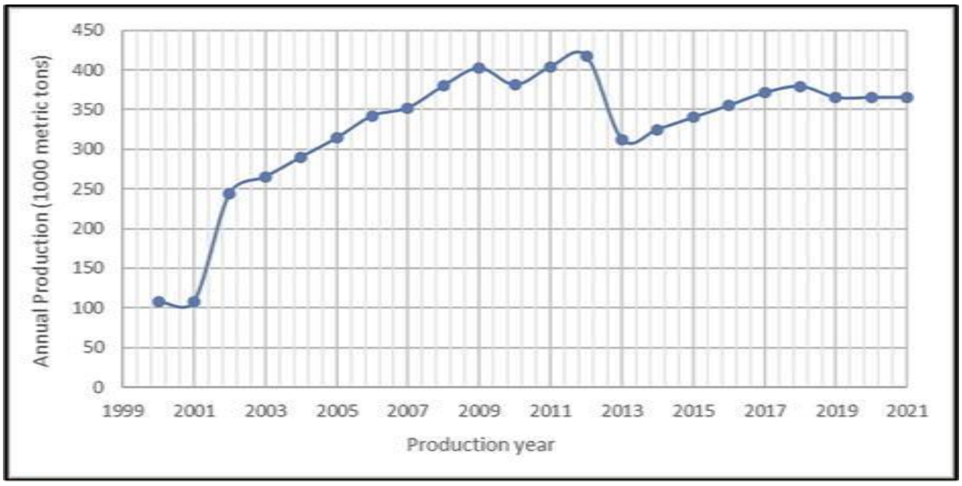



**Figure 1.1: Annual palm oil production of Ghana from 2000-2021 (IndexMundi, 2018)**

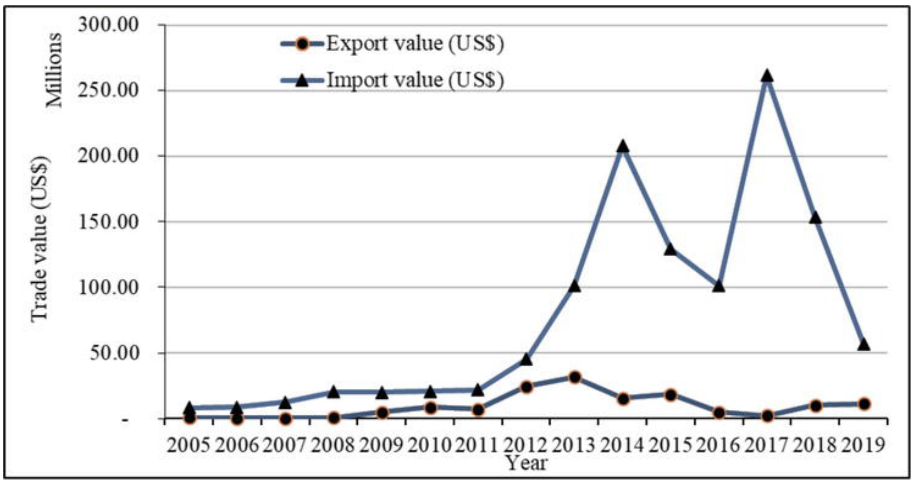


**Figure 1.2: Commercial value of export and import of Palm oil in Ghana (IndexMundi, 2018)**

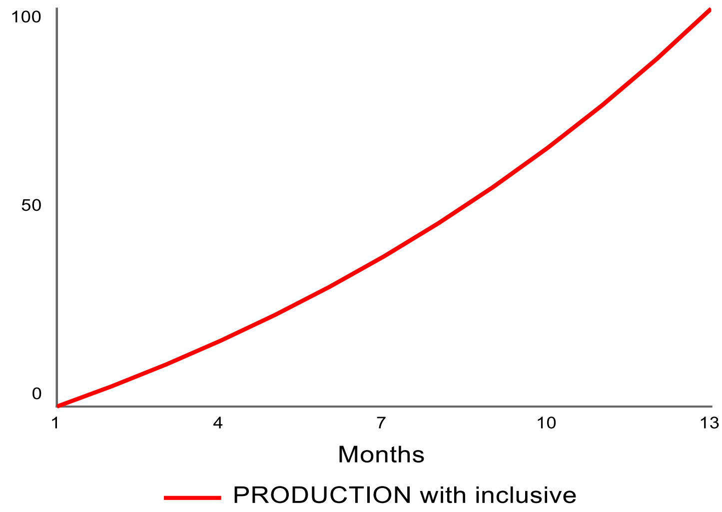



**Figure 1.3: Non RSPO production after policy**

Above is the desired production this study seeks to achieve after the use of the recommended policies.

## 1.3 Background

Continuous and increasing demand for palm oil for both household and industrial purposes has made oil palm cultivation an important sector in the economic development of many developing countries, as poverty alleviating avenue and mitigating shortage of food issues. On the other hand, increased oil palm cultivation has put considerable strain on forestlands (Teoh 2010) and concern is rising over the negative environmental and social impacts of large-scale cultivation of oil palm (Boons and Mendoza 2010). The leading environmental problems associated with palm oil referred to as conflict palm oil by activists include, but are not limited to, the following: habitat destruction, forest burning, air pollution, soil erosion, deforestation, and loss of biodiversity (Clay 2013).

It is reported that a high number of palm oil farms operate informally without legal land tenure, are non-compliant with health and safety regulations, and evade tax payments among other business and legal risks. Major environmental concerns linked to palm oil farms include deforestation, biodiversity loss and water depletion. The biggest underlying threats are the lack of effective laws relevant to CSR and/or weak enforcement of the law. The expansion of oil palm worldwide is unparalleled by any other vegetable crop. Accordingly, as consumer awareness of social and environmental devastations linked to the industry has risen, certification mechanisms have grown as a way to implement checks and measures in sustainable palm oil production. This work will explore the opportunities and obstacles to sustainable palm oil production in Ghana the role that independent smallholders could hold through Roundtable on Sustainable Palm Oil (RSPO) palm oil certification schemes. This research will also contribute to the understanding and the role that independent smallholders hold in the development of palm oil plantations in Ghana. Farmers can choose to cultivate independently or sign a contract with the recently RSPO-certified local mill, the Juaben Oil Palm Development Company (JOPDC). Farmers under the certification program have access to RSPO and JOPDC extension services, loans, and inputs, independent smallholders do not have access to support, extension services, or training whereas those who are not under this program do not get any support of form of training from this program. Studies have showed that farmers who are under this program believe they do not have adequate training for cultivating palm.

In order to enhance the effectiveness and legitimacy of palm oil production, positive involvement of independent smallholders is critical to this growing industry in implementing safeguards to protect and conserve social and environmental actors (Groom et al. 2008; Schoneveld et al. 2010; Lee et al. 2011). It is therefore necessary for a rapid expansion of oil palm cultivation in West Africa to meet global demands in a more sustainable manner. This research therefore seeks to evaluate the implications of palm oil production and the role of sustainable practices among small scale farmers in Ghana. This study therefore seeks to attain the following objectives:

- Identify opportunities for creating a sustainable palm oil production to meet industrial and household consumption.
- Analyse ways to increase palm oil production.
- Accessing the RSPO certification program and its impact on production.

By examining these issues, the study will come out with policy recommendations and implementation strategies to enable the government identify the best sustainable strategies to address the increasing demand of palm oil. As well as identifying the best production policies and investment opportunities to bridge the production gap among small scale palm oil production. Policy recommendations are listed below:

- RSPO certification mechanism without the inclusive of small-scale farmers.
- RSPO certification mechanisms that involves all small-scale farmers.

The second chapter provides an overview of literatures in line with the RSPO certification program and palm oil. The third chapter will explain methodology employed, model description and data used. The fourth chapter will discuss the analysis and the policy employed in this study. Finally, the last chapter will explain the results and findings of the study and the implications as well, also provide recommendations for further studies and research.

# CHAPTER TWO

## 2.1 Literature Review

Palm oil is a major agriculture commodity in most countries, it accounts for 34 percent of the world's annual production of vegetable oil and 63 percent of the global exports of vegetable oils. It is produced in tropical climates and in 42 countries across the world. Palm fruit from which palm oil is extracted is of immense value. Agriculture employs about 65% of the workforce in Sub-Saharan Africa. It is estimated that production in Ghana is about 230,000 metric tons in the year 2020. (USDA,2021). Palm oil is a key agricultural commodity in Ghana and production is mainly by the small-scale farmers in the community. (Amponsah et al., 2018). It accounts for a significant portion of the country's economy. Its production seems to have both social and economic impacts which includes creation of employment and generating income (Amponsah et al., 2018).

## 2.2 A Brief History of Oil Palm in Ghana.

Historically, Ghana was one the first country to produce palm oil on large scales for exportation and through this some technologies and techniques were established in the country to help with production. Some of these technologies and ideas were later transferred to other palm oil producing countries such as Malaysia and Indonesia to aid them in their production (Fold and Whitfield, 2012). The country's first international commercial of palm oil started in the year 1820 due to the direct demand of palm oil which was caused by the industrial revolution that occurred in Europe and palm oil production became the country's main export. (Agbodeka, 1992). As the price of palm oil declined all over the world in the 1870s, this made it difficult for the country to produce competitively, palm oil still accounted for about 75% of export revenue by the country in the 1880s (Danyo, 2013, p. 159). After Ghana gained independence from Britain in 1957, all the successive governments to be elected in Ghana have continually promoted oil palm production as a major industrial crop for both local consumption and exportation as well (Adjei-Nsiah et al., 2012). There have been different attempts to promote and rejuvenate the palm oil sector in Ghana since the 1950s, but most of these have either delayed or also failed at the long run. The most outstanding measure that seemed to have worked is the Presidential Special Initiative (PSI) on Oil Palm which was launched in 2002 by John Kufour of the National Patriotic Party (NPP) the then government of

Ghana, the same party currently in power. The Ex President had a vision that the Presidential Special Initiative will help the small-scale production of palm oil and substantially mitigate rural poverty, and the fact that the country has a good geographical and economic location to help re-develop a feasible export industry for palm oil. The objective of the PSI-Oil Palm programme was to start an increase in the already existing palm oil industry which is led by the government by promoting the expansion of lands cultivated by the small-scale farmers, associating them with existing processing mills, inviting investors to develop or build new processing mills and also to upgrade the existing processing mills in the communities and encouraging farmer ownership of these new mills. According to Asante (2012), after three years of implementing the PSI, it started failing until it was totally unreliable. This happened as a result of public and private elite influence during negotiations, making of policies, decision making, implementation and the outcomes. At the time the PSI-Oil Palm approach was launched, the benefits and support to be received by these rural farmers had been outlined in the strategy already. But these benefits that had been outlined were conflicting with (behind the scenes) public-private stakeholder elite agreements. This left the government to be deprived of funding as well as support from the private sector to ensure the continuation of the project. Several measures were put in place to main manage and maintain the program, but they all failed after five years of implementation. When the government was re-elected into power again in 2016, the came with a renewed interest in the palm oil industry and this time it was coupled with a key interest environmental sustainability and certification. The New Patriotic Party (NPP),the then political party in power partnered with key NGOs, and other prominent stakeholders in the country along the supply chain to ensure the promotion palm oil production with the goal of increasing national development while synchronously helping rural communities have access to sustainable and diverse livelihoods.

## 2.3 A Multi-Functional Crop, Palm oil

A multi-functional crop is a crop is grown not for just one purpose, but several benefits and palm oil identify as a multifunctional crop. They are grown to provide more than one significant purpose like conservation, fuelwood, shade, fibre, fodder, or medicine. Ghana's long history in the production of palm oil has manufactured a varied production systems which have co-existed to this present day. Ranging from the collections palm nuts which accounts as a non-timber forest product (NTFP), through agroforestry and mixed crop production has led to the domestication of oil palm for local processing and local trade that has led to the establishment of industrial plantations for the purposes of exportation as an internationally traded commodity to generate revenue for the nation. (FAO and OECD, 2016). The production of palm oil generates a wide range of products on the markets such as food, fibre, soaps, and other products used by households and bio-energy production as well. Considering the day-to-day activities of most rural households, palm oil plays a major role. It is utilized in the everyday in both rural and urban households in the country and is consumed both domestically by households and on an industrial level too (Angelucci, 2013; Ofosu-Budu and Sarpong, 2013). The palm is able to produce two types of oils which are, the oil which comes from the fruit of the nut and is mostly referred as the fresh fruit bunches (FFB) and the palm kernel oil (PKO) which generates from the nut inside of the kernel. The oil that we get from the fresh fruit bunches has wide and diverse usage both internationally and in Ghana which includes the manufacturing of food products, cosmetics products, and detergents. The fibre and shells from the fruit are recycled into fuel for mill boilers. Expellers from the palm kernel can also be used in the energy and animal production sector in terms of feed and is supplied in a traditional manual household production and small-scale, informal, and a semi mechanized production (FAO and OECD, 2016). Palm kernel oil also serves as a type of cooking oil which used in the preparation of some cuisines in the country such as stews, soups and used as an all-purpose cooking oil. In Ghana, the sap from oil palm is consumed and is popularly known as palm wine or allowed to ferment to form a more potent alcohol also popularly called akpeteshie (Amoa-Awua et al., 2007; Phalan, 2010). About 60% of crude palm oil production is generated from the small-scale farmers and account for 85% of the planted area (Opoku and Asante, 2008; Osei-Amponsah et al., 2012), which is estimated to be 400,000 hectares approximately under oil palm cultivation (Foli, 2010 cited in Fold and Whitfield, 2012). The production of palm oil does not only provide income and livelihoods to farmers, but to other stakeholders. These stakeholders include mill operators, transporters/drivers, seed distributors, agro-input sellers, the non-industrial palm oil kernel processors, and others who work at the industrial-scale palm processing and about 1,000 to 3,000 contractors who are employed especially during harvest season. (Awusabo-Asare and Tanle, 2008). Currently there is just a little information about how the energy sector utilizes palm oil. The biofuel policy currently focuses solely on Jatropha (Duku et al., 2010).

Focusing on potential for biofuels taking into consideration the four major traditional crops grown in Ghana specifically, Palm oil, sweet sorghum, maize and cassava, there is a possibility for these crops to replace about 9.3% of transportation fuels as of 2020 and 7.2% by 2030 (Kemausuor, et al., 2014). The motivation to establish feasible Export Industry for palm oil production is to be able to produce enough palm oil for exportation to reach the main importers like China and India because production has not been able to reach the demands of these countries. Exportation in Ghana is currently focused on niche markets in Europe and neighbouring countries in West Africa (Fold and Whitfield, 2012). The country's crude palm oil production (CPO) is at about 245,000mt which is insufficient to meet the demands of the country's market. As a result of its insufficient production to meet the demand of the nation, over 30,000 mt of crude palm oil (CPO)is imported annually from Asia to make up its national CPO deficit. Economic Community of West African State (ECOWAS) has a CPO deficit of 850,000 mt as well (Government of Ghana, 2011; MASDAR, 2011; International Trade Centre, 2012), and is a net importer of palm oil (International Trade Centre, 2012). The ECOWAS region is part of the Tropical Forest Alliance 2020 Africa Palm Oil Initiative, that is working towards producing sustainable palm oil, and is already trading between its members (Proforest, 2019), this alliance already has provided a continental market that is economically incentive in invigorating the palm oil sector in Ghana. The government has planned to increase its production through the RSPO as it encourages best management practices and also increase its exportation to the ECOWAS and the other international markets. The RSPO certification program is the route to certified palm oil and also designed to increase oil palm production for both industrial processing and commercial purposes. The country has about five major plantations which are all certified under the RSPO. With the increasing demand for RSPO certified products, land available for the expansion of palm oil still remains limited. About 70% of fresh fruit bunches that the mills process is provided by independent small-scale farmers, thus measures to improve the production as well as requirements to meet the certification program of the small-scale farmers have become a major concern. These small-scale farmers do not have enough financial capacity to obtain certification but yet without certification they are excluded from the international palm oil supply chain (RSPO, 2019). After the RSPO Smallholders Support Fund (RSSF) was introduce in 2013, six initiatives have been implemented around the world and two of these six initiatives were done in West Africa, Ghana, and Nigeria to be precise. The intention of the RSSF is to support smallholders with the RSPO certification program and to facilitate their access to international markets that are increasingly guaranteeing strict policies of buying only certified sustainable palm oil produce. Palm oil and palm kernel represents 2% of agricultural production value of Ghana in 2010. Its processing serves as a major source of income and employment to many people. In 2015, employment by the palm oil production was estimated to be over two million people. Palm oil produced by small-scale industry is mainly processed into vegetable oil which is used in most of the dishes consumed by Ghanaians. Data from the Ghana Demographic and Health Survey in 2008 showed that one out of every two households in the country uses palm oil in the preparation of food. And this accounts for about 54% of the country's population.

Production in Ghana continues to be monopolized by small-scale farmers within areas that is less than three hectares, which does not make it lucrative for foreign investors and other foreign firms to engage in deals with them. (Felgenhauer and Wolter 2009). Considering the use of use of the contract farming or out-grower schemes, foreign and local companies, as well as foreign investors find their work to be appealing and are able to deal with this challenge productively. Small-scale farmers with contract can now enter into long-term and short-term agreement with the milling companies in their locality. The milling companies also in provides some benefits to these farmers to help increase their productivity. These benefits include supporting them through training on the best and appropriate management practices (BMP) and provision of financial grants such as loans for them to invest in their farms. The loans granted to these farmers are deducted from final payments when feedstock is delivered (Von Maltitz and Staffor 2011). The out-grower schemes serve as a temporal trade agreement where the firms are to ensure the supply of palm oil products by the small-scale farmers. These schemes offer improved authority over supply and are frequently used by firms operating in the Ghanaian palm oil sector (Felgenhauer and Wolter 2009). When the preliminary difficulties of trust and logistics are defeated, out-grower schemes will be able to provide the firms with authority over the operations and also improving the conditions of contract small-scale farmers production (Felgenhauer and Wolter 2009). The out-grower scheme has been itemized in Indonesian and Malaysian palm oil development plans and other agricultural areas in Africa.

Large-scale plantation and the out-grower schemes have been combined to help promote and increase local ownership and also to benefit the farmers (Diaz-Chavez 2011). This type of collaboration between the contract small-scale farmers and the firms has the tendency to promote rural development in the communities they find themselves, the transfer of technologies from the firms to the farmers and also assimilate them into the nation's economy (Glover 1984; Barrett 2008; Collier and Dercon 2014).

Currently, the involvement of independent small-scale farmers is a major problem affecting the implementation of the certification schemes and the production of sustainable palm oil in some developing countries (Lee et al. 2010). These farmers own land in the catchment area around the mill but since they do not have signed contracts to help them supply their fruits, they harvest to the mills to be processed. The farmers do not get trees or do they receive inputs and loans. Since they do not have any contacts, they are completely independent and cultivate and produce

oil palm strictly through their own methods, devices, and knowledge. As a result, the lack monitoring compliance, support from farm extension officers and higher financial resources. All these make their work difficult and tend to affect their productivity which deter large palm oil companies from establishing deals with independent smallholders (von Hage2011).
Although some NGO's have considered to involve independent small-scale farmers in the production palm oil, the stated potential benefits of these systems are considered as hypothetical, and in reality, these independent small-scale farmers are excluded entirely. Following the increasing demand for palm oil production from consumers, importing and exporting countries and industries, the government of Ghana has generated a program to accelerate the agricultural modernization program targeting mechanisms that will take into consideration of small, medium, and large-scale agricultural production (Antwei et al. 2010). Palm oil plays a key role in the development strategy for economic growth in some developing countries with over 636,000 households in rural communities engaged in its cultivation in Ghana (Adjei 2014). According to Dogbevi (2009), As it stands now, Ghana is yet to establish policies, regulations, or structures in place for the palm oil industry, giving rise to a scramble for land to cultivate palm oil for export. Since the introduction of the promotion of palm oil by the government of Ghana, and voluntary nature of certification schemes, the industry seems to be growing but without a solid mechanism for protection and certification.

## 2.4 Round Table for Sustainable Palm Oil

The Roundtable for Sustainable Palm Oil (RSPO) is a non-profit organization that was established in 2004 with the sole aim of promoting the growth and use of sustainable palm oil products through global standards and multistakeholder governance. It was established in response to growing environmental and social concerns surrounding palm oil production. The organization included, growers, processors, traders, consumer goods manufacturers, retailers, bank, and NGO's. The RoundTable for Sustainable Palm Oil is currently the only certification program that is recognized globally and operating in the global palm oil industry. It was established based on the principles of ensuring a sustainable palm oil production and it has been able to integrate the concerns and interests of the civil society in terms of palm oil production through the governing structure of the scheme. During the late 1990s, the World Wild Fund which was established in Switzerland in 1961 decided to mobilise all stakeholders and key actors in the palm oil supply chain. RSPO started operating fully in 2004 after several years strategic deliberations were made. It began operating as private regulatory scheme in the palm oil production industry with a  clear target on the global market. RSPO has achieved an exceptional recognition in the palm oil industry globally and all the areas certified under the RSPO continues to increase in their productivity. The RSPO is a prime example of the emergence of private governance schemes in the agriculture industry intending to further sustainable development. The lack of government intervention and proper regulation of the industry made way for consumer-oriented businesses, partnered with civil social organisation and palm oil producers to address long-term threats to the industry. RSPO has commenced a process of fundamental change in the oil palm industry with respect to both policy and practice that is productive in an inherently unsustainable industry.

## 2.5 Acceptance of Round table for Sustainable Palm Oil (RSPO) certification

After the establishment of the RSPO, stakeholders have witnessed a tremendous growth having about 2,633 members coming from 78 countries as well as issuing 328 trademark licenses to other countries and members (RSPO 2016a). A General is held annual by the stakeholders, members, and key players in the palm oil production industry such communities are invited to discuss the development that has resulted from RSPO. Challenges that were faced during the implementation of RSPO is also discussed to seek the right solutions towards achieving the aim which is a sustainable palm oil production. The certification has many features that has highlighted the advantages of the program since its introduction over ten years in terms of membership, growth in certified acreage, increases in the number of companies that have adopted RSPO certification, and an increase in involving almost all  smallholder in production sector of palm oil. Since the introduction of the scheme, it has been recorded globally that it has  over 3.46 million hectares of land that are fully registered under RSPO certification. This accounts for about12.89 million tonnes of certified sustainable palm oil (CSPO) that is produced which is also 20% of the global palm oil production (RSPO 2016b). Despite the tremendous growth in its membership, the certification program had a vision to continuously expand and have all palm oil production industry globally under its certification in 2020. RSPO continues to become of the largest palm oil certification program that takes sustainability into consideration and continues to ensure advancement in the program since its establishment. According to a study by Paoli et al. (2010), the supply chain must adhere to the sustainable measures such as practices that would not cause deforestation, ensure that all workers receive fair wages, land acquisition should be done through legal means. RSPO advanced the idea of a sustainable supply chain industry and then launched a process of fundamental transformation in their policies and practices (Paoli et al. 2010). There has issues of illegal and corrupt transactions between some of the production companies and some third-party certifier working for RSPO (Laurance et al. 2010; Paoli et al. 2010; Schouten and Glasbergen 2011; Nesadurai 2013).

## 2.6 Roundtable for Sustainable Palm Oil in Ghana.

The Roundtable for Sustainable Palm Oil (RSPO) certification scheme was established in Ghana back in 2008 with the primary objective of incorporating and promoting sustainable practices in Ghana among farmers and all essential stakeholders in the palm oil industry. After the introduction of the certification scheme in Ghana, studies have showed that the certification scheme has started gaining a lot of recognition among some of the farmers and key actors of the palm oil industry leading to a n increase adoption of the program by some palm oil producers. This recognition has helped to achieve the aim of promoting sustainable practices in the industry, which is the ultimate goal of the RSPO certification scheme.

However, a recent study conducted by Amponsah et al. (2021) has revealed that the adoption of the RSPO certification system has been slow in Ghana, with many smallholder farmers being unaware of the program or failing to see the value in pursuing certification. While larger palm oil producers have shown some interest in the certification, smallholder farmers remain the primary barrier to the adoption of sustainable practices in the industry. This lack of awareness and interest among smallholder farmers poses a significant challenge to the RSPO certification system in Ghana.

Another study by Egyir et al. (2020) has highlighted additional challenges facing the RSPO certification system in Ghana. These challenges include a lack of infrastructure and technical expertise to support sustainable practices, as well as limited access to finance and markets for certified products. Additionally, the authors note that stronger government policies and incentives are necessary to promote sustainable palm oil production in Ghana.

Despite these challenges, there have been some successful examples of RSPO certification in Ghana. One notable example is the Twifo Oil Palm Plantations Limited (TOPP), which has achieved RSPO certification for its operations in the Western Region of Ghana. TOPP has implemented a range of sustainable practices, including the use of environmentally friendly fertilizers and pest control measures, as well as social programs to support local communities.

This success story demonstrates the potential of the RSPO certification system to promote sustainable palm oil production in Ghana.

Overall, the literature suggests that while the RSPO certification system has the potential to promote sustainable palm oil production in Ghana, there are significant challenges to its adoption. Addressing these challenges will require greater awareness and education among smallholder farmers, as well as stronger government policies and incentives to support sustainable practices in the palm oil industry. Therefore, concerted efforts by all stakeholders are necessary to ensure the success of the RSPO certification scheme in promoting sustainable practices in the Ghanaian palm oil industry.

## 2.7 Benefits of Roundtable for Sustainable Palm Oil in Ghana.

The adoption of sustainable practices in the palm oil industry is vital to reduce negative environmental impacts, such as deforestation and loss of biodiversity, and promote social responsibility by ensuring fair labour practices, community development, and respect for the rights of indigenous peoples and local communities. One way to achieve this goal is through RSPO certification, which is highly beneficial for the palm oil industry in Ghana. RSPO certification allows producers to access new markets for certified palm oil products as consumers become increasingly aware of the environmental and social implications of palm oil production.

According to a recent case study by the RSPO, the Twifo Oil Palm Plantations Limited (TOPP) in Ghana has experienced several advantages from achieving RSPO certification. TOPP has gained access to new markets for their certified palm oil products, as well as improved relationships with local communities and stakeholders. TOPP has also made significant improvements in environmental performance, including the reduction of chemical use and better waste management.

It is essential to recognize that the promotion of sustainable practices in the palm oil industry is an ongoing effort. RSPO certification serves as a crucial step towards this goal, but it requires continued commitment and cooperation from all stakeholders to achieve long-term sustainable outcomes. The adoption of sustainable practices in the palm oil industry can contribute to a more environmentally and socially responsible industry and promote economic growth and development in Ghana.

One of the key benefits of RSPO certification in Ghana is the promotion of sustainable practices in the palm oil industry. This includes reducing the negative environmental impacts of palm oil production, such as deforestation and loss of biodiversity. RSPO certification also encourages social responsibility by promoting fair labour practices, supporting community development, and respecting the rights of indigenous peoples and local communities. Another benefit of RSPO certification is increased market access for certified palm oil products. As consumers become more aware of the environmental and social impacts of palm oil production, there is growing demand for sustainably produced palm oil. RSPO certification can help palm oil producers access these markets and differentiate their products from non-certified palm oil. According to a case study by the RSPO (2020), the Twifo Oil Palm Plantations Limited (TOPP) in Ghana has experienced several benefits from achieving RSPO certification. These include increased market access for certified palm oil products, as well as improved relationships with local communities and stakeholders. TOPP has also seen improvements in environmental performance, with reduced use of chemicals and improvements in waste management.

# CHAPTER THREE

## 3.1 Methodology of the study.

Looking at the interest of this study and the aim of gaining insight and understanding palm oil production and the RSPO scheme a mixed-methods research strategy was adopted. And this because the mixed-methods research strategy allows the combination of qualitative and quantitative approaches (Denscombe, 2012). After reviewing a couple of literature, the of relationships between the systems and parts underlying the producing of palm oil and RSPO scheme was gained, and this made it possible to identify important factors in the system that have significant influence on production. This gave an insight on how to build a model that will replicate all the factors or systems that have been identified. And looking at complexity of the agriculture system in terms of understanding, a system dynamics model that can represent all the processes that goes on in the production of palm oil in comprehensive and rational manner was built. We develop a system dynamics (SD) model to replicate the historical data and design policies. According to Ford, 1999; Sterman, 1994 & 2000, using system dynamics as a research methodology gives a clear- cut in-depth learning about dynamic and complex problems. The sole aim of using system dynamic simulation model for this project is to give stakeholders a live representation of problem and also make it easy for them to understand how changes in a one or more factor or variable in the system will influence other factors. And also make it easy for policy makers to simulate the policy to know how it works and help them in decision making since the model makes it possible to simulate over years how policies will work. The application of System dynamics modelling as research method in the field agriculture specifically in palm oil isn't new and that this method prioritizes integrity and nonlinear properties of complex systems and that it is very suitable to model crude palm oil supply chain (Suryani et al., 2018).

Another study that used system dynamics suggest that it is auxiliary tool to represent a system with causal loop diagram to identify relationships among variables and feedback loops that exist in the system (Campuzano and Mula, 2011; Bala et al., 2017). According to Handaya et al., ( 2022) soft systems dynamics methodology (SSDM) which is a key feature of system dynamics is an ideal modelling technique for studying very complex and multivariate systems. Although System Dynamics has been used in various research on palm oil in many countries, there are a few studies that have used System Dynamics and therefore this study will give pave way for other  researchers in Ghana to look at System Dynamics when conducting similar studies.  The simulation software that was used in this study is Stellar Architect which helped in the building of the model and conduct all simulations. Finally, the model that has been built has provided a structure that palm oil production as well as the RSPO scheme in Ghana and all internal dynamics that occurs the industry and thus makes it easy for stakeholders to identify problems and make better decisions. The model was set to simulate from 2020 and projected to 2040 and the policy will be introduced in 2025. This model was built to not to predict the future used as a policy tool that can help in making decisions. This model will help policy makers and stakeholders test different assumptions, explore other policies, and also examine the impact of their decisions. When developing the model,  not all the data required was gained but reasonable assumptions have been made so as to replicate the problem since it's difficult to get all relevant data from developing countries like Ghana. System dynamics is applicable in the production because,  their feedback loops, time delays between cause and the effects and non- linear relationships exists.

## 3.2 Model Structure

Model development and structure from a system dynamics approach is simply refers to the stocks, flows which are the inflows and the outflows and other exogenous variables. These are the main building blocks of a system dynamic model. Model represents both the qualitative and the quantitative aspects of a system. The model structure outlines the overall framework and organization of the system dynamics model. It defines the relationships, interactions, and dependencies among the various components of the agricultural sector under consideration. The model structure is typically represented using stock and flow diagrams, causal loop diagrams, or other visual representations that illustrate the feedback loops and feedback mechanisms within the system. Understanding the model structure is crucial for comprehending the dynamics and behaviour of the variables within the model.

### 3.2.1 Stocks

According Sterman, (2000, p.192) Stocks are accumulations which represent the state of the system and generate the information upon which the decisions and actions are based". In other words, stock accumulates the difference between the inflow to a process and its outflow. Or in a layman's perspective they are variables in which quantities accumulates or are collected over time. Stocks only increase through the inflow which means the inflow is what is being accumulated in the stock over time. And the only way to influence a stock is through the inflows and outflows.

### 3.2.2 Flows

Flows are the variables that influences the stocks. They simply add into a stock or takes out from a stock. Flows can be in two forms in a model either and inflows or an outflow. The inflow is the variable through which the stock accumulates, or it simply fills the stock, and the outflow is the variable through which the stock depletes or decreases. The outflow simply takes out from the stock whiles the inflow fills the stock.

### 3.2.3 Causal Loop Diagrams (CLD)

Causal loop diagrams are important in system dynamic models. They help in representing the feedback structure of systems. CLDs represent a system using three basic elements, that can in be boxes, connections or causal links, and feedback loops. The connections or causal links, represent causal influence, from one node to the other which is either positive or negative. Positive causal links implies that they increase or decrease together, and the negative causal links or connections also implies that they change in opposite directions, if one goes up, the other goes down, and vice versa. The figure below is an example of a CLD.

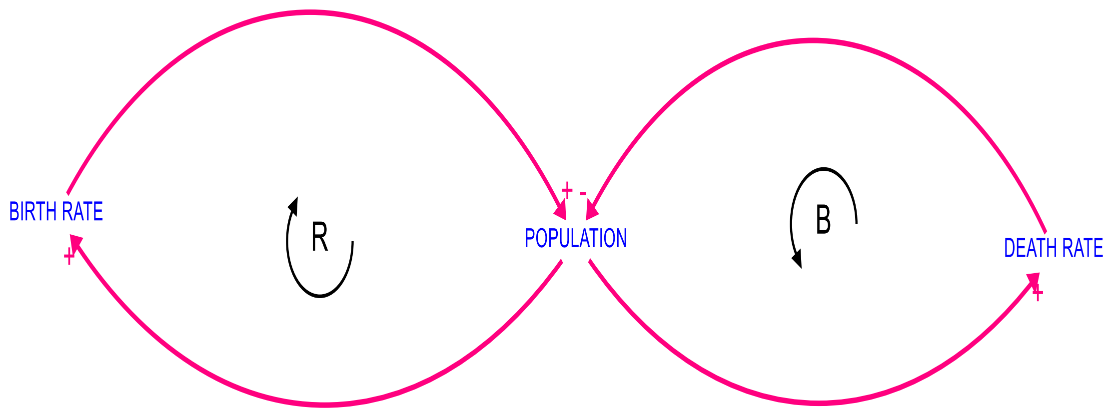



**Figure 3.1: Population CLD.**

### 3.2.4 Exogenous or Auxiliary variable

Auxiliary variables or Exogenous variables represent external parameters. These external parameters are outside of the system's influence. They are also intermediate steps by which stocks and flows affect each other through feedback mechanisms. Auxiliary variables add conceptual clarity to the model by describing the intermediate steps by which stocks and flows are related. The figure below represents stock, flows and exogenous variable.

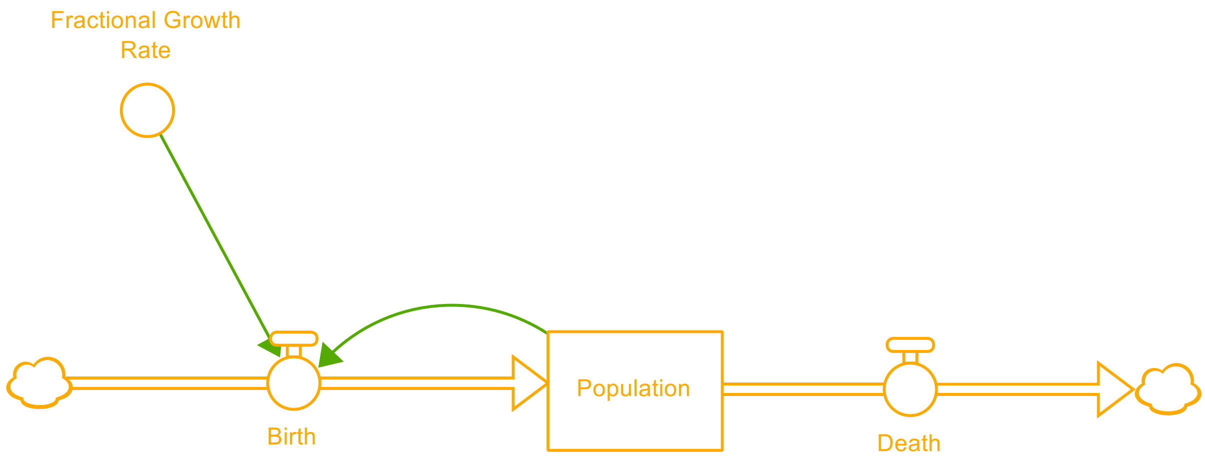



**Figure 3.2: Stock and flow with exogenous variable.**

In the above figure3.1, the arrow labelled "Birth" on the left side represents a flow, specifically an inflow, as it represents the rate at which new individuals are added to the population. The rectangular shape labelled "Population" represents a stock, which is the accumulation of individuals over time. The flow of "Birth" contributes to increasing the stock of the population over time.

On the other hand, the arrow labelled "Death" on the right side represents a flow, but this time it is an outflow, as it represents the rate at which individuals are removed from the population due to mortality. The "Death" flow decreases the stock of the population by reducing the number of individuals.

The circle at the top labelled "Fraction Growth Rate" is an exogenous or auxiliary variable. It represents an external variable that influences the growth rate of the population. It is not directly connected to the stocks or flows but serves as a factor that affects the dynamics of the system.

In summary, the diagram illustrates how stocks and flows relate in the model. The "Birth" flow adds individuals to the "Population" stock, while the "Death" flow removes individuals from the population. The "Fraction Growth Rate" exogenous variable influences the growth rate of the population, indirectly affecting the stocks and flows within the system.

### 3.3 Model Assumptions

To address the lack of data and enable the model to replicate the problem at hand, certain reasonable assumptions were made. These assumptions were necessary to provide a basis for understanding and analysing the dynamics of the system being discussed. These assumptions may include estimations, generalizations, or hypothetical scenarios that align with the context of the problem.

By making reasonable assumptions, the model can simulate and explore the relationships and behaviours within the system, even in the absence of complete or specific data. These assumptions serve as placeholders to illustrate the dynamics and interactions among the variables, allowing for meaningful analysis and insights to be generated.

These assumptions were made to facilitate the modelling process and should been validated. Overall, the reasonable assumptions made aim to bridge the data gap and enable the model to replicate and analysed the problem effectively, offering insights and potential strategies within the given context. The model incorporates assumptions that indicate a maximum quantity of nutrients, machines, knowledge, and water will have a higher effect on yield. These assumptions suggest that there is an optimal level or threshold for these variables, beyond which increasing their quantity will lead to a greater impact on yield.

For example, in the case of nutrients, the assumption is made that there is a maximum amount of nutrients that can be effectively utilized by the crop. Increasing the nutrient availability beyond this threshold will not further enhance yield. Similarly, for machines, knowledge, and water, the assumption is made that there is an optimal level where their increased quantity will have the greatest positive effect on yield.

These assumptions reflect the concept of diminishing returns, where increasing inputs or factors up to a certain point can lead to significant improvements in yield, but beyond that point, the additional benefits diminish. By incorporating these assumptions, the model considers the nonlinear relationship between these variables and yield, acknowledging that there are limits to their effectiveness.

## 3.4 Model Building

This sector is going to be about the description of all structures, or the variables used in building the model. This chapter will help apply or demonstrate the structures in a system dynamic model that has been listed in the previous section (model structure). The key variables in this will be listed and reasons will be given as to why they are key variables. The time horizon of the study will be stated as well and the also the model structure and feedback loops which will help understand the model.

## 3.5 Key Variables

Key variables are the most influential and critical factors that significantly affect the behaviour and outcomes of the system. These variables play a pivotal role in shaping the dynamics and patterns observed in the agricultural sector. The selection of key variables is be based on their relevance to the research question, availability of data, and their potential impact on the overall behaviour of the system.  The key variables in the study are RSPO farmers and Non RSPO farmers, Palm oil inventory, RSPO farmers production, Non RSPO farmers production, Production and Harvesting Machines, Knowledge, and Irrigation infrastructure.  RSPO farmers are the farmers who have contracts with RSPO certification scheme and the Non RSPO farmers are the farmers who have not signed a contract with the RSPO certification scheme.

## 3.6 Time Horizon

The time horizon of the study refers to the period for which the model is designed to simulate and analysed the dynamics of the palm oil production. The time selected for the model building will enable the model show or replicate the reference mode and also it is long enough to be able to show any shortcomings of the policy designed for the study. The time horizon in this study is 20 years. The model will estimate production in 2020 to 2024 then policy will start in 2025 to 2040.

## 3.7 RSPO Farmers

The RSPO farmers' structure focuses on farmers who have signed under the RSPO certification program. These farmers receive various benefits from the program, including training, financial support, harvesting and processing services, and irrigation services. These benefits are designed to improve their agricultural practices and overall productivity. One key variable in this structure is the RSPO farmers' yield, which represents the amount of palm oil produced by the farmers who are part of the RSPO certification program. This variable is influenced by several factors, including the adoption of improved farming techniques, access to training and knowledge, availability of nutrients, and the support provided by the certification program.

Another variable is palm oil production by RSPO farmers, which represents the total volume of palm oil produced by the farmers under the RSPO certification program. This variable is affected by the aggregate yield of RSPO farmers and the number of farmers participating in the program. Additionally, variables related to knowledge and nutrient availability are included in the RSPO farmers' structure. Knowledge availability refers to the access farmers have to training, information, and best practices provided by the RSPO certification program. Nutrient availability represents the availability and proper management of essential nutrients required for palm oil production, such as fertilizers and soil amendments. These variables interact within the RSPO farmers' structure, creating feedback loops. For example, the training and support provided by the certification program can enhance farmers' knowledge and skills, leading to increased yield and palm oil production. Higher yields, in turn, can motivate more farmers to join the RSPO certification program, expanding the overall production and impact.

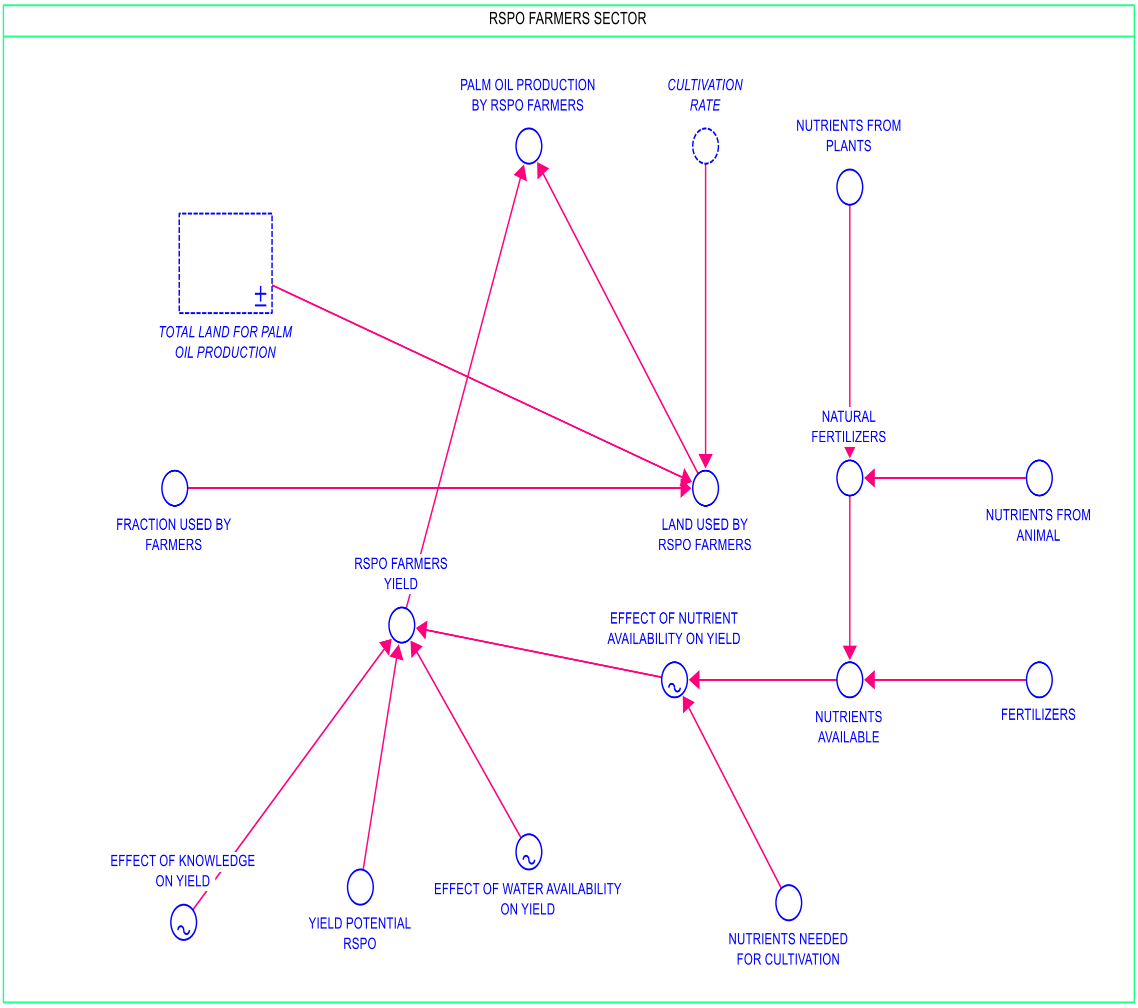



**Figure 3.3: RSPO farmers production sector**

This structure represents the production sector for RSPO farmers. A detailed explanation of all the variables will be given in the sector.

The variable palm oil production by RSPO farmers represents the combined production of all farmers participating in the certification program. This variable is influenced by various factors, indicating that production relies on the variables depicted in the aforementioned figure, and any changes in these variables will impact production. There are two main variables connected to this production: the land utilized by RSPO farmers and the yield of RSPO farmers. The land used by RSPO farmers is also influenced by two variables: the fraction of land used by farmers and the total land used for palm oil production. The land used by RSPO farmers signifies the overall land size utilized by all farmers in the certification program. The fraction of land used by farmers represents the proportion of land utilized by farmers out of the total land used for palm oil production. It is worth noting that this study focuses specifically on small-scale farmers or holders, as there are other industries involved in palm oil production.

RSPO farmers' yield represents the average yield per hectare of land used for production. It depends on five variables: RSPO yield potential, the impact of machines on RSPO yield, the effect of knowledge on yield, the influence of water availability on yield, and the effect of nutrient availability on yield.

RSPO yield potential refers to the maximum achievable yield under optimal growing conditions. The impact of machines indicates the efficiency of machinery in production. The use of machines, such as tractors, enables farmers to work more efficiently and increase their production. For instance, using machines for tasks like tilling soil is faster than relying on manual labour, leading to improved harvest.

The effect of knowledge on yield highlights the importance of farmers possessing the necessary knowledge and expertise in areas such as soil health, crop rotation, and irrigation. Having updated techniques and technologies in farming allows farmers to make informed decisions about land management, resulting in higher yields compared to those without such knowledge.

The effect of water availability on yield is determined by the amount of water accessible for production. It is influenced by three variables: rainfall per hectare, water from irrigation per hectare, and water required for cultivation. Rainfall per hectare denotes the total amount of rain received per hectare of land. Water from irrigation per hectare represents the amount of water supplied from external irrigation sources. Lastly, water required for cultivation refers to the total amount of water needed for palm oil cultivation.

The effect of nutrient availability on yield represents the impact of nutrient levels in the soil on yield. It is influenced by two variables: available nutrients and nutrients needed for cultivation. Available nutrients indicate the total nutrients present for cultivation, while nutrients needed for cultivation represent the actual amount of nutrients required for growing palm oil. Available nutrients, in turn, depend on the variable of natural fertilizer and synthetic fertilizers. Natural fertilizer comprises nutrients derived from plants and animals, such as compost and manure, which enhance soil health by increasing organic matter and promoting beneficial microbial activities that improve yield. Synthetic fertilizers, on the other hand, are artificial fertilizers required for cultivation.

In summary, the variables discussed encompass the complex relationships involved in palm oil production by RSPO farmers, including factors such as land usage, yield, the impact of machines, knowledge, water availability, and nutrient availability.

## 3.8 Modelling Non RSPO farmers.

The structure of Non RSPO farmers is similar to that of RSPO farmers, with the key distinction being that Non RSPO farmers operate independently and do not avail themselves of the services provided by the RSPO scheme. As a result of their independent status and lack of access to RSPO benefits, their structure is relatively smaller and more simplified compared to RSPO farmers.

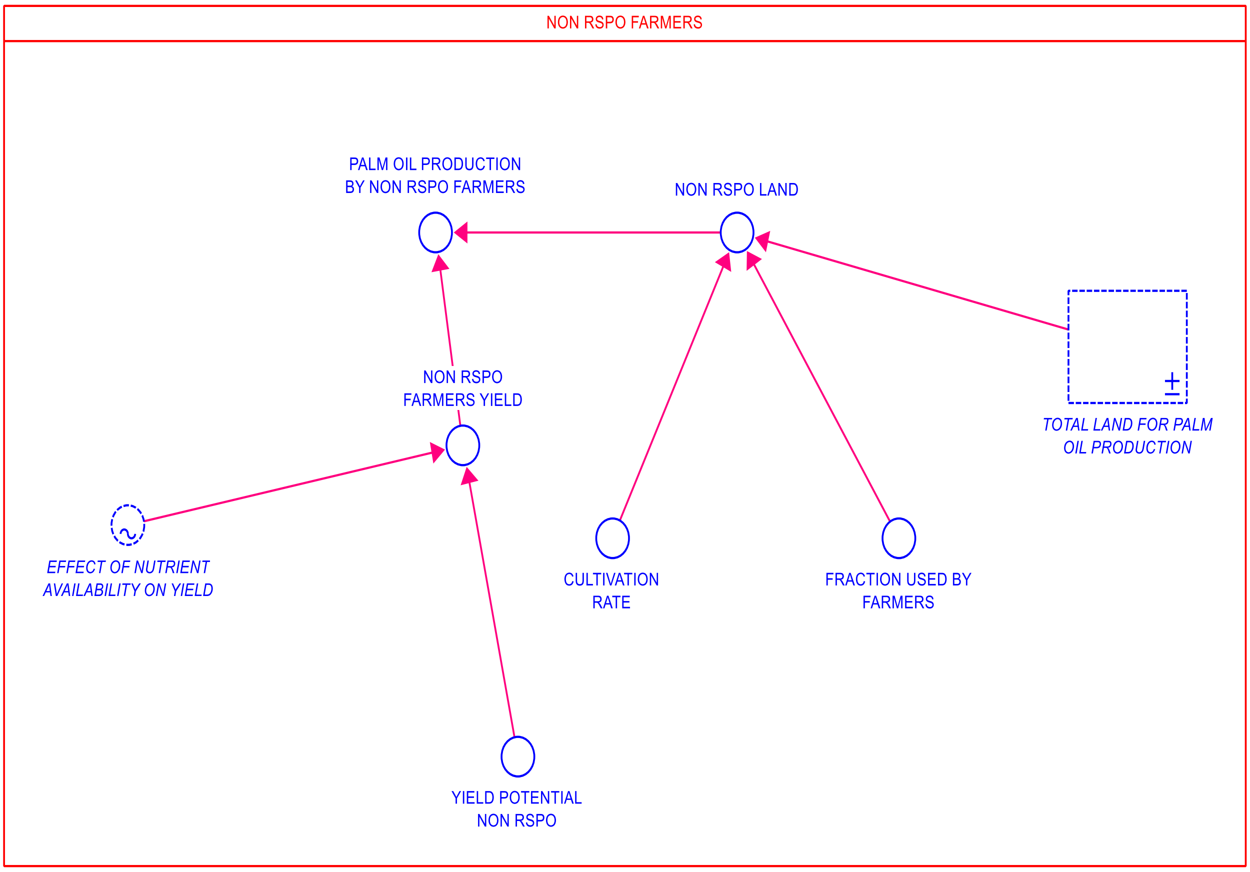



**Figure3.4 : Non RSPO farmers production sector**

This structure represents the production sector for Non RSPO farmers. A detailed explanation and role of all the variables will be given in the sector is given below:

The structure outlined above pertains to the production sector for Non RSPO farmers. It encompasses the variables and their roles in this sector:

Palm oil production by Non RSPO farmers refers to the total amount of palm oil produced by farmers who are not part of the RSPO certification program. This variable serves a similar purpose as in the RSPO farmers' sector. It also relies on two variables: Non RSPO land and Non RSPO farmers' yield.

Non RSPO farmers' land signifies the overall land area utilized by independent farmers who are not part of the RSPO program. It is influenced by other variables, including cultivation rate, the total land used for palm oil production, and the fraction of land utilized by the farmers.

Non RSPO farmers' yield represents the yield of palm oil produced per hectare of land by Non RSPO farmers. It is dependent on two variables: yield potential and the effect of nutrient availability on yield.

Yield potential refers to the maximum achievable yield under optimal growing conditions for Non RSPO farmers. It represents the highest possible amount of palm oil that can be produced when all factors are ideal.

The effect of nutrient availability on yield indicates the influence of nutrient levels present in the soil on the yield of Non RSPO farmers. It considers the quantity of nutrients available in the soil and how it affects the yield of palm oil.

In summary, the structure described above outlines the key elements of the production sector for Non RSPO farmers, including variables such as palm oil production, Non RSPO farmers' land, Non RSPO farmers' yield, yield potential, and the effect of nutrient availability on yield.

## 3.9 Modelling Machinery and Knowledge Sector

Machinery and Knowledge sector represents some of the benefits RSPO farmers receives from being part of the scheme. The use of machines in farming increases efficiency and productivity and knowledge also helps farmers make best decisions about crop management, soil health and other important factors that can help improve yields. Farmers who use precision agriculture technologies like GPS and yield monitors are able to increase their yields. As stated in chapter two, from reviewed literature it was observed that the farmers under the certification program gets some benefits from it. Some these benefits are training from extension on good farming practices, soil health, availability of farming and processing machines. Good farming practices like cover crops and conservation tillage practices are able to improve soil health and also reduce erosion. Below is the machinery and knowledge sector, a detailed explanation of all the variables will be given.

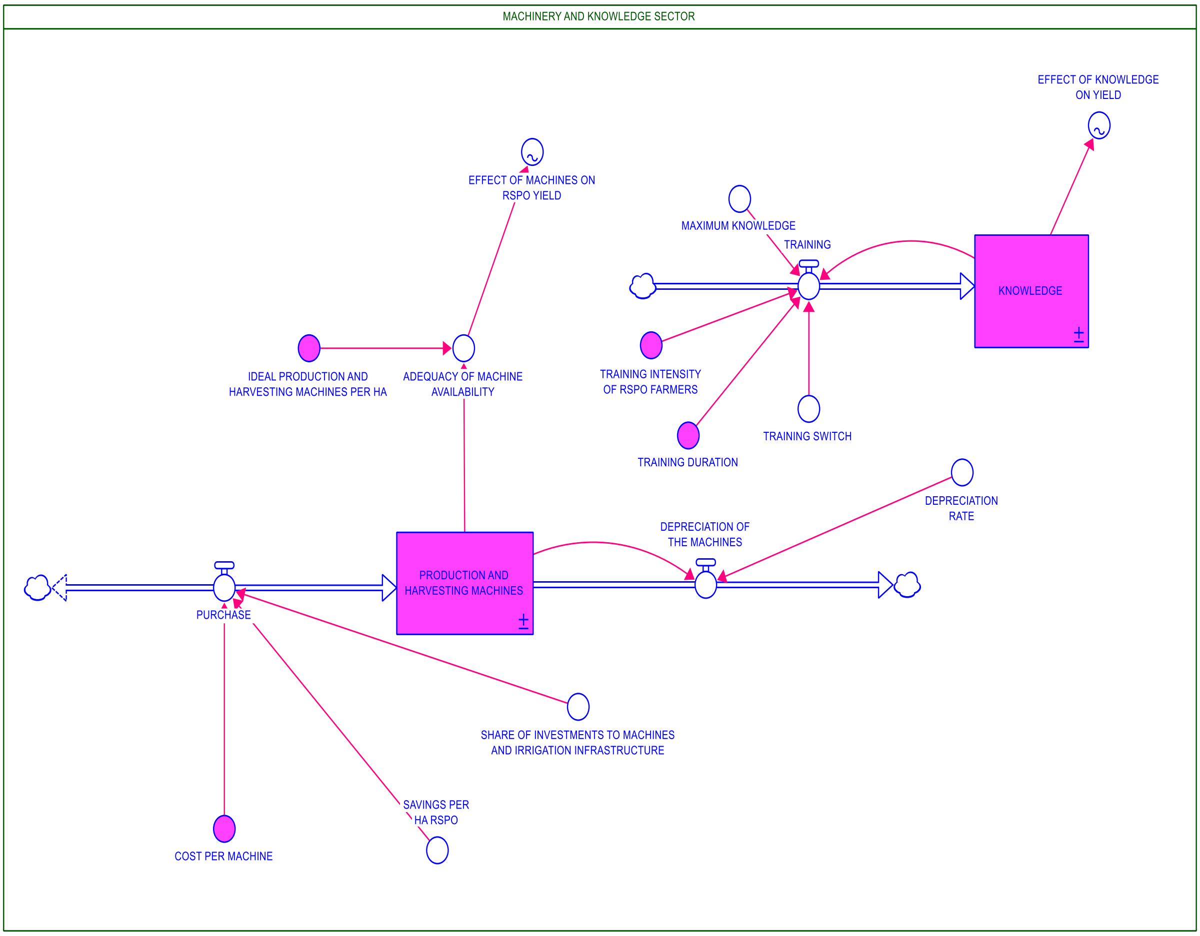



**Figure 3.5: Machinery and Knowledge Sector**

In the above structure there are two stocks namely production and harvesting machines and knowledge. Production and harvesting machines stock represents the total number of machines that is available and this stock increases through a variable named purchase. As it was explained in the previous part of this chapter, stocks only increase through an inflow and decreases through an outflow. The inflow is purchase and it is also dependent on other variables like cost per machines, saving of RSPO Farmers and share of investment to machines and irrigation infrastructure.

Cost per machine is the average cost per machine used the production. Share of investment to machines and irrigation is the percentage of revenue that has allocated for investing into production that is used for machinery and irrigation purposes. Saving per RSPO is also the amount of money that RSPO farmers are able to save. The outflow of the production and harvesting machines is depreciation of machines. As the name implies, when machines are used for some time then tend to depreciate which the machines value or efficiency reduces and at a point in time would not be useful anymore. The depreciation rate represents the speed at which the value of machines depreciates over time.

The depreciation of machines is also dependent on number of machines available and depreciation rate. Adequacy of machines availability is another variable in this sector, and it impacts the variable effect of machines on RSPO yield. Adequacy of machines availability refers to whether there are enough machines to the needs of farmers. This variable is dependent on the stock of harvesting and production machines and ideal production and harvesting machines per ha. Idea production and harvesting machines represents the possible number of machines that is needed for palm oil production.

Knowledge is another stock in this sector, and it presents the level of training the farmers have acquired. This stock has an inflow which increases the stock. The inflow is training, and it depends on other factors namely: maximum knowledge, training switch, training duration and training intensity. Training switch is simply when training starts. Training duration is how long the training takes. Maximum training serves as guide to how training is conducted, it is the desired level of training farmers need to improve their productivity. Training intensity refers to the level of effort that is used or put into the training process. Effect of knowledge on yield is dependent on knowledge which means the level of knowledge and how abreast the farmers are with new information regarding farming will determine how they will make decisions in terms of production.

## 3.10 Modelling Irrigation Sector

This sector represents the irrigation sources that is used by farmers under RSPO certification program. Palm oil require a lot of water since it is a fast-growing crop that has high productivity and biomass production. Therefore, farmers cannot rely on only rainfall for cultivation, and they must have supplementary source to meet the water required for palm oil. Ghana has two main seasons, the rainy season and the dry. As their names implies there much rain during the rainy season and less rain during the dry season. Irrigation plays a vital role in agriculture by supplying water to crops when rainfall is insufficient or inconsistent.  In order for farmers to have enough water for their crops, they need to have another source of water which they rely on throughout the year. The annual water requirement of palm oil production is 1300mm. Below is a structure representing the irrigation sources used.

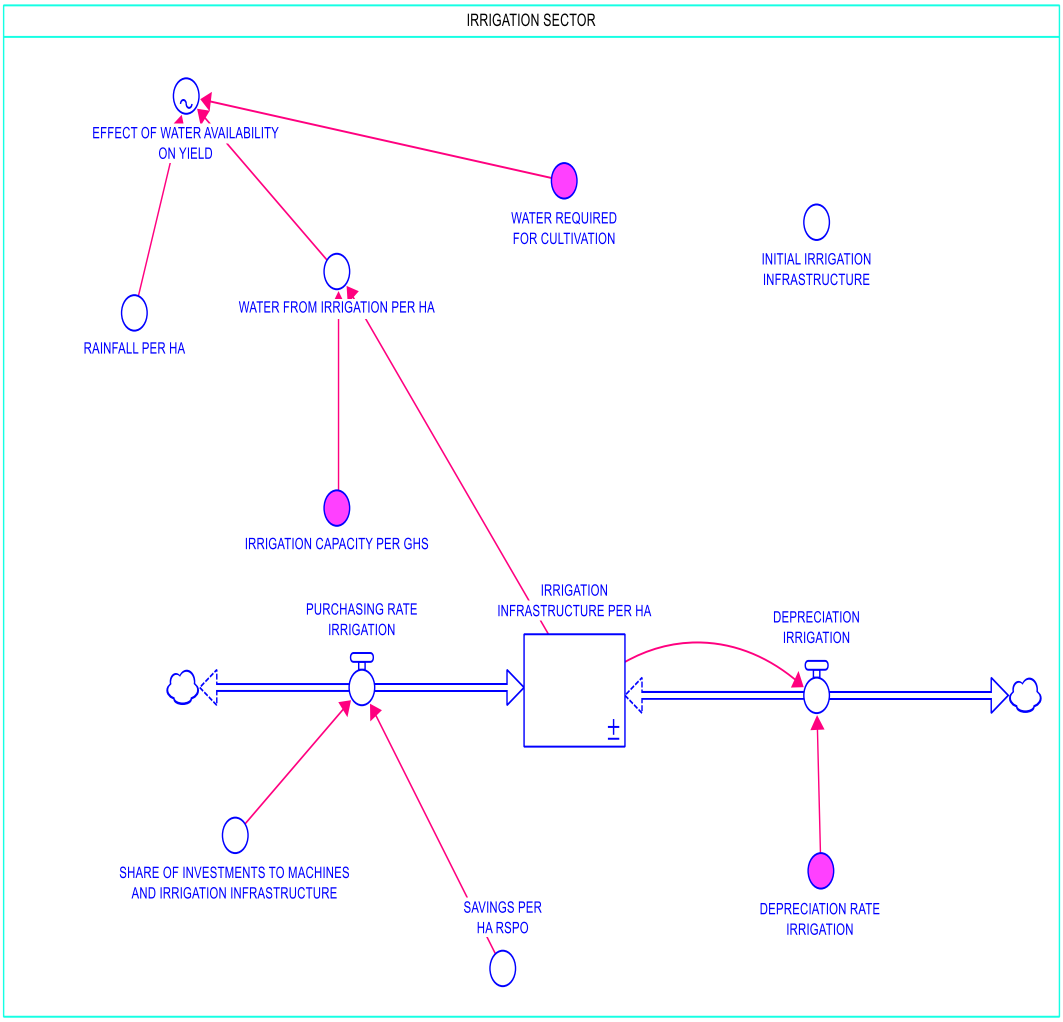



**Figure 3.6: Irrigation Sector**

This structure consists of a stock representing the irrigation structure per hectare (ha), with an inflow and an outflow. The variable recognizes that the availability and proper use of irrigation systems can significantly impact farmers' yield in several ways:

Water supply: Adequate irrigation ensures a consistent and reliable water supply for crops throughout their growth stages. This helps prevent water stress, ensures optimal plant growth, and minimizes yield losses due to drought conditions.

Nutrient distribution: Irrigation systems can be designed to incorporate the application of fertilizers or nutrient-rich solutions, enabling efficient distribution of essential nutrients to plants. Proper nutrient management through irrigation supports healthy plant development, leading to improved yields.

Soil moisture control: Irrigation allows farmers to regulate and maintain appropriate soil moisture levels for optimal plant growth. By providing sufficient moisture in the root zone, irrigation helps plants access water for vital physiological processes, such as nutrient uptake and photosynthesis, which can positively influence yield.

Crop health and disease control: Irrigation can help manage plant diseases by maintaining proper moisture levels and reducing stress conditions. By avoiding water-related plant diseases or providing controlled conditions, irrigation can contribute to healthier crops and higher yields.

The structure described in the text represents a system focused on irrigation infrastructure and its impact on crop yield. It consists of several interconnected components:

Stock: The stock in this system represents the irrigation structure per hectare (ha) of land. It serves as a reservoir that holds the quantity of irrigation infrastructure available for use.

Inflow: The inflow into the stock is determined by two variables. The first variable is savings per RSPO farmers, which represents the amount of money saved by RSPO farmers for investment purposes. The second variable is the share of investment allocated to machines and irrigation infrastructure. It signifies the portion of the savings that is designated specifically for purchasing machines and improving irrigation infrastructure. The inflow represents the rate at which RSPO farmers invest in their irrigation structure to ensure a sufficient water supply for their production.

Rate of Irrigation: This variable reflects the rate at which RSPO farmers invest in their irrigation structure. It is influenced by the savings per RSPO farmers, and the share of investment allocated to machines and irrigation infrastructure. The more savings and higher investment allocation, the greater the rate of investment in the irrigation structure.

Outflow: The outflow from the stock is represented by the variable "depreciation irrigation." It is influenced by two factors: the stock of irrigation infrastructure and the depreciation rate. Depreciation irrigation represents the decrease in the value of the irrigation infrastructure over time due to wear and tear. The higher the stock of irrigation infrastructure and the higher the depreciation rate, the greater the outflow of depreciation irrigation from the stock.

Depreciation Rate: This variable determines the rate at which the value of the irrigation infrastructure decreases over time. It represents the impact of wear and tear on the infrastructure and influences the rate of outflow from the stock.

Water from Irrigation per ha: This variable represents the amount of water used for irrigation per hectare of land. It is determined by two factors: the variable "irrigation capacity per GHS" and the stock of irrigation infrastructure. Irrigation capacity per GHS signifies the amount of water that the irrigation system can deliver based on the available funds. The higher the irrigation capacity per GHS and the larger the stock of irrigation infrastructure, the greater the water flow for irrigation per hectare of land.

Effect of Water Availability on Yield: This variable assesses how the availability of water impacts crop yield. It is influenced by three factors: rainfall per ha, water required for cultivation, and water from irrigation per ha. Rainfall per ha represents the amount of rainwater that falls on one hectare of land. Water required for cultivation signifies the amount of water necessary for growing palm crops. The variable "water from irrigation per ha" represents the amount of water provided through irrigation for one hectare of land. The combined effect of these factors determines the impact of water availability on crop yield.

In summary, this system incorporates various elements such as savings, investment, depreciation, and water availability to model the dynamics of irrigation infrastructure and its impact on crop yield.

### 3.11 Modelling Land Sector

The land sector is an important component in many systems particularly in this study which focuses on agriculture specifically palm oil production. The land sector represents the physical area of land available for cultivation. Below is the land sector for this study.

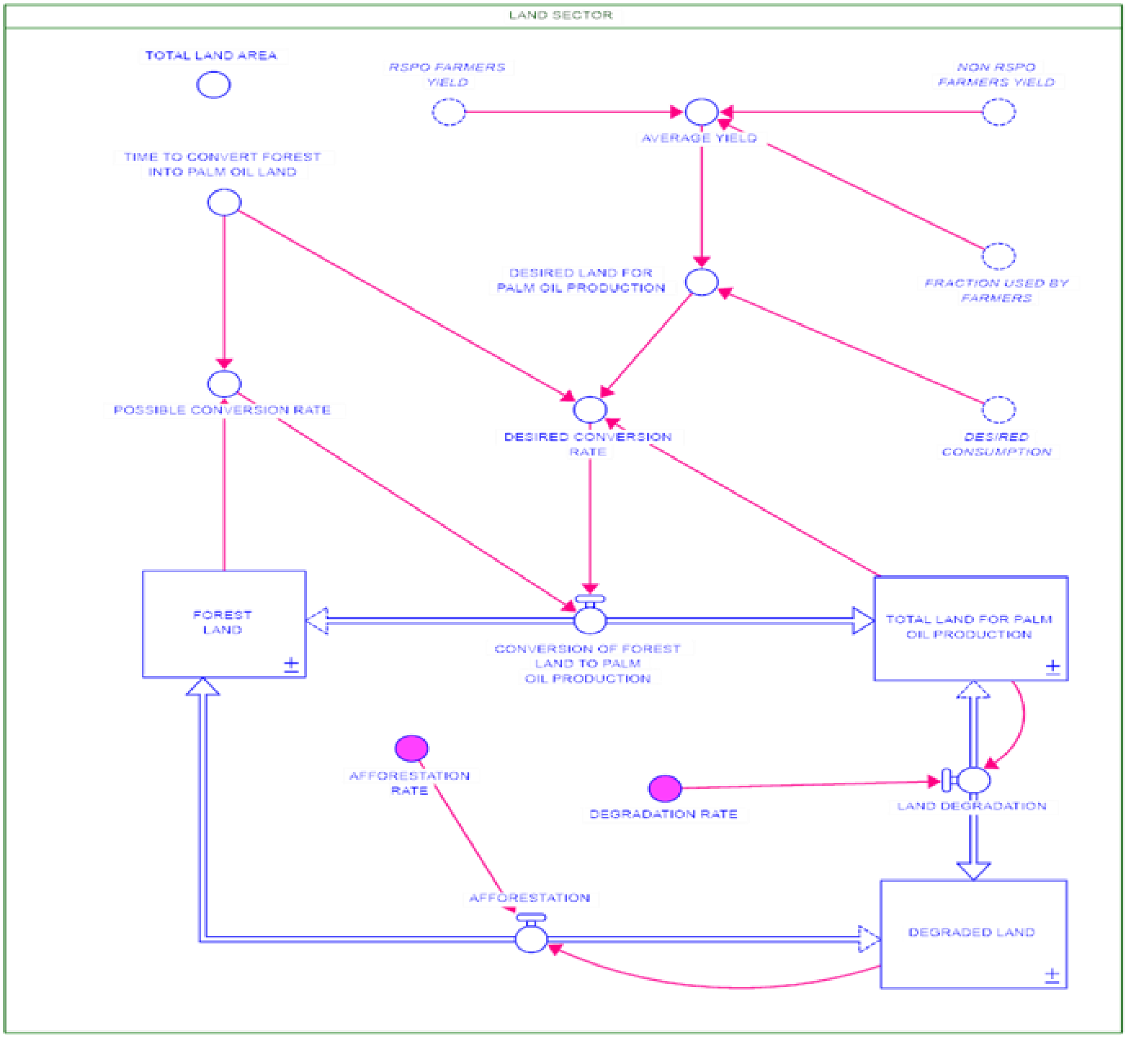



**Figure 3.7: Land Sector**

This sector discusses the land related to the production of palm oil. Within this sector, there are several key elements to understand. The sector consists of three stocks: forest land, total land for palm oil production, and degraded land. These stocks represent the quantities or amounts of each type of land.

Forest land refers to the land covered by forests. It has two associated flows: Conversion of forest land into land for palm oil cultivation: This involves taking land from the forest land stock to use it for palm oil production.

Afforestation: This is the process of increasing the forest land stock by establishing new forests.

Afforestation rate: This rate measures how quickly new forests are created on available land. When afforestation occurs, the forest land stock increases accordingly.

Degraded land: Degraded land refers to areas that have been abandoned or have deteriorated to the point where they are no longer suitable for farming. The degraded land stock represents the quantity of such lands.

Land degradation: Land degradation is the process by which land quality declines over time. It acts as an outflow from the land for palm oil cultivation stock, as land becomes degraded, and serves as an inflow to the degraded land stock.

Degradation rate: This rate reflects the speed at which land quality diminishes over time.

Conversion of forest land into land for palm oil production: This variable involves transforming forest land into land suitable for palm oil cultivation. It depends on two key factors:

Desired conversion rate: This rate indicates the desired speed at which forest land should be converted into agricultural land. It relies on the desired land area for palm oil production, the total land available for palm oil production, and the time it takes to convert forest land to palm oil land.

Possible conversion rate: This rate represents the maximum rate at which forest land can be converted into palm oil land. It depends on the amount of forest land available, and the time required for the conversion process.

Desired land for palm oil production: This refers to the land area necessary or preferred for palm oil production. It is influenced by the desired consumption level of palm oil and the average yield of palm oil per hectare of land.

Average yield: This measures the quantity of palm oil produced per unit of land (hectare) by all farmers. The average yield depends on factors such as the yield of farmers who comply with the Roundtable on Sustainable Palm Oil (RSPO), the yield of farmers who do not comply with RSPO standards, and the fraction of palm oil used by farmers.

Desired consumption: Desired consumption represents the amount of palm oil needed to satisfy the demand for palm oil.

In summary, this sector provides a detailed explanation of the stocks (forest land, total land for palm oil production, degraded land) and the relationships between them, as well as the variables (afforestation rate, land degradation, conversion rates, average yield, desired consumption) that influence these stocks.

## 3.12 Modelling Revenue and Expenditure Sector

This sector is responsible for all monetary aspect of the model. This sector shows how revenue from production is used and how it impacts production as well. A detailed description of all the variables in the sector is given. Below the structure for the revenue and expenditure sector.

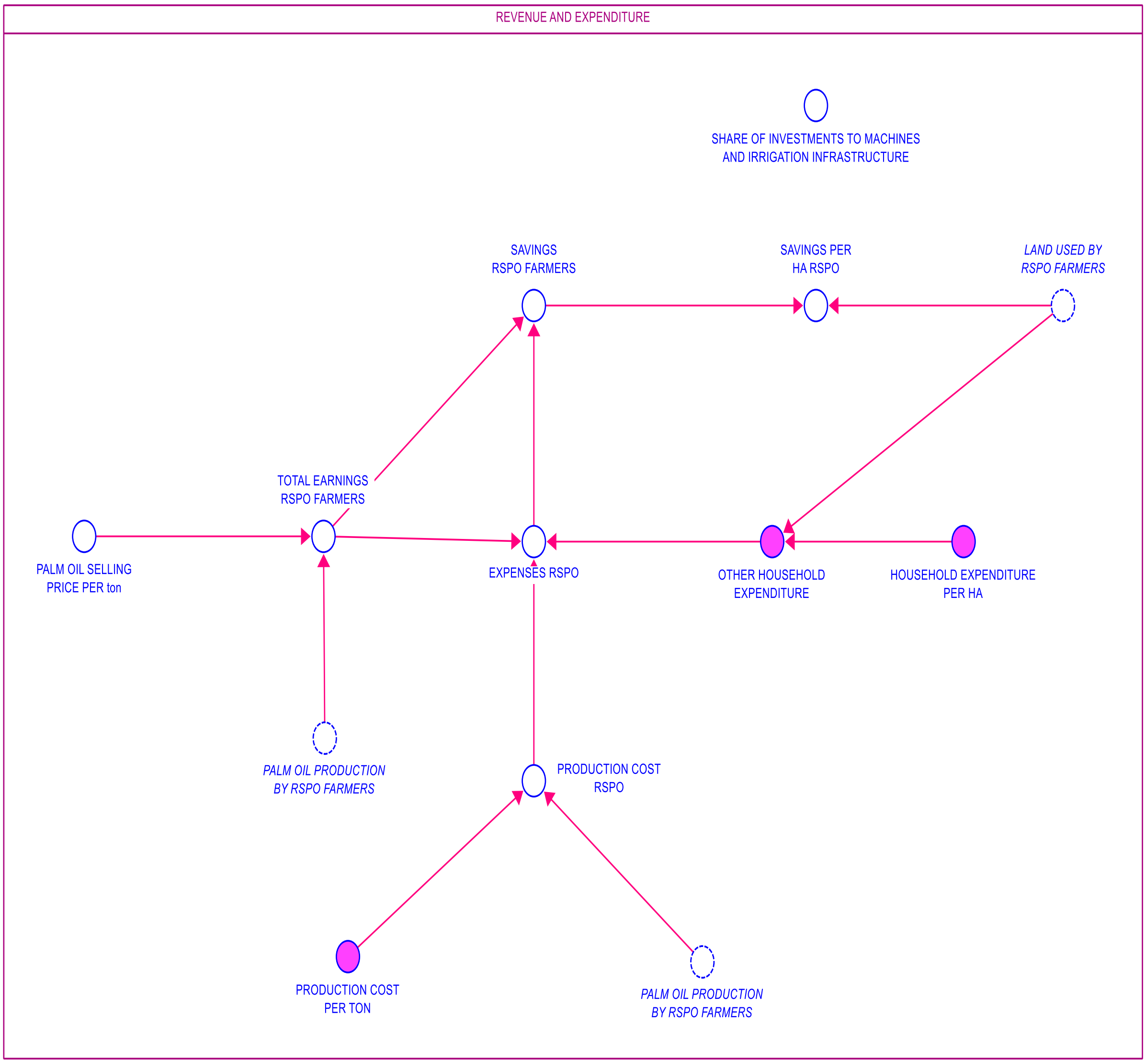



**Figure 3.8: Revenue and Expenditure Sector**

Share of investment to machines and irrigation infrastructure represents the percentage of revenue for investment that is allocated to machines and infrastructure. Savings RSPO farmers represents the money set aside for other purposes. This variable is dependent on total earnings RSPO farmers and expenses RSPO. Total earnings RSPO farmers represents the amount of money RSPO farmers have earned over a period of time from their production. Expenses RSPO represents the cost associated with palm oil production. Savings per ha RSPO represents the money that has been saved from the revenue obtained per hectare (ha). Palm oil price selling per ton and palm oil production per RSPO determines the total earning RSPO farmers. Selling price per ton represents the amount money that is charged per ton of palm oil. Production cost RSPO represents the total amount of money used in the production process. This is dependent on two variables: production cost per ton and palm oil production RSPO. Production cost per ton represents the cost of production per ton. Other household expenditure represents the amount of money spent on goods and services. The variable is determined by land used by RSPO farmers and household expenditure per hectare (ha).

## 3.13 Modelling Inventory Sector

This sector is responsible for stocks of palm oil that has been produced by both RSPO farmers and Non RSPO farmers and exported palm oil. A description of the variables in the sector is given below.

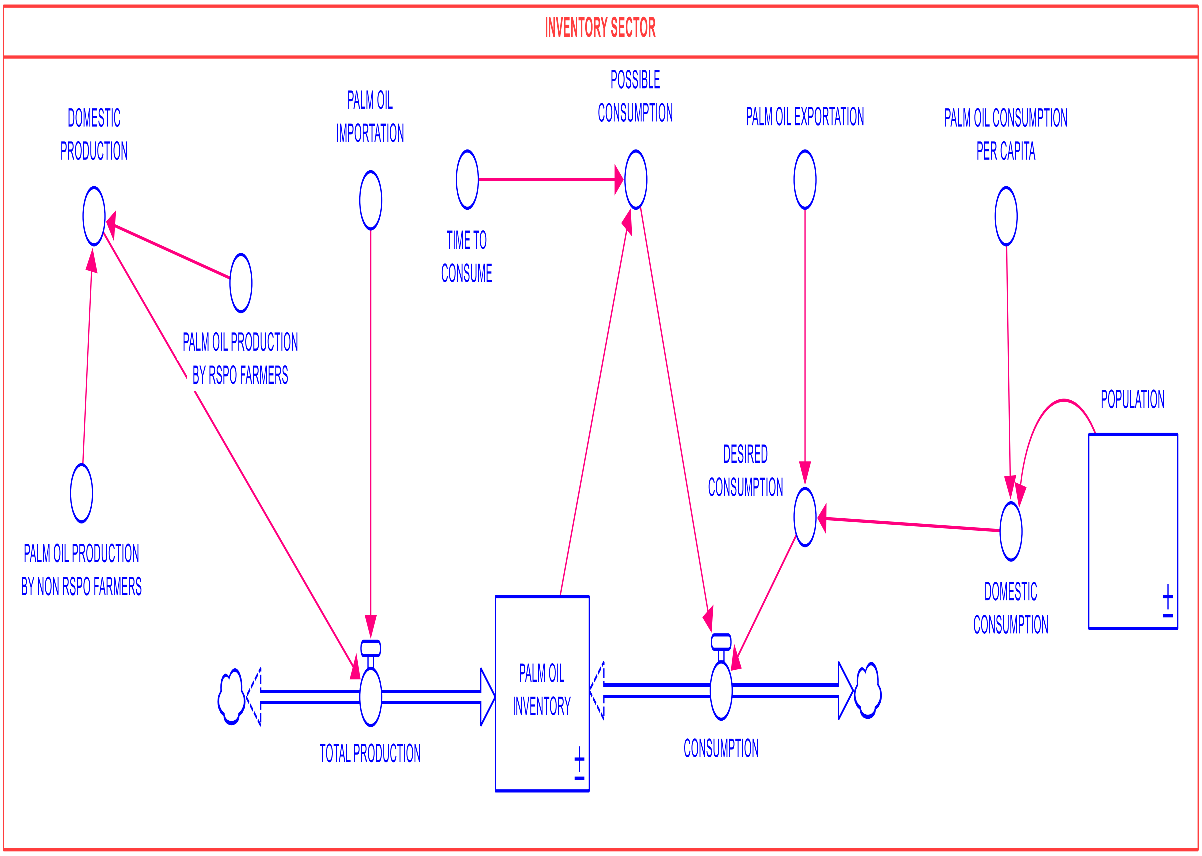



**Figure 3.9: Inventory Sector**

In this structure, there are two stocks that is palm oil inventory and population. Palm oil inventory is a stock with two flows: total production and consumption. Palm oil inventory represents the total value of palm oil that has been produced by the RSPO farmers and the non RSPO farmers as well as exported palm oil. Total production serves as an inflow here and through it the palm oil inventory increases. Total production is determined by domestic production, which is a function of RSPO farmers production and non RSPO farmers production and palm oil importation. It is a sum of the total production of RSPO farmers, the Non RSPO farmers and imported palm oil. Palm oil importation represents the total value of palm oil that was imported.

The outflow consumption represents the value of palm oil that is consumed or used. This is determined by the desired consumption and the possible consumption. Possible consumption represents the maximum value of palm oil that can be consumed, and it is a function of the available palm oil which is the palm oil inventory and time which time to consume. This means consumption is based on the palm oil that is available in the inventory since you cannot consume what you don't have. Desired consumption is a function of domestic consumption and palm exportation. Domestic consumption is a function population and palm oil consumption per capita, and it represents the amount of palm oil that is consumed. Palm oil exportation represents the amount of palm oil that exported to meet the demands. Palm oil consumption per capita represents the average amount of palm oil that is consumed by an individual. Population represents the total number of people living in a particular area.

## 3.14 Modelling Population Sector

In this structure serves as a sub sector of the inventory sector since it did not play so much role in the model. Its major role was to help determine consumption. Below is the population sector and a detailed description is given.

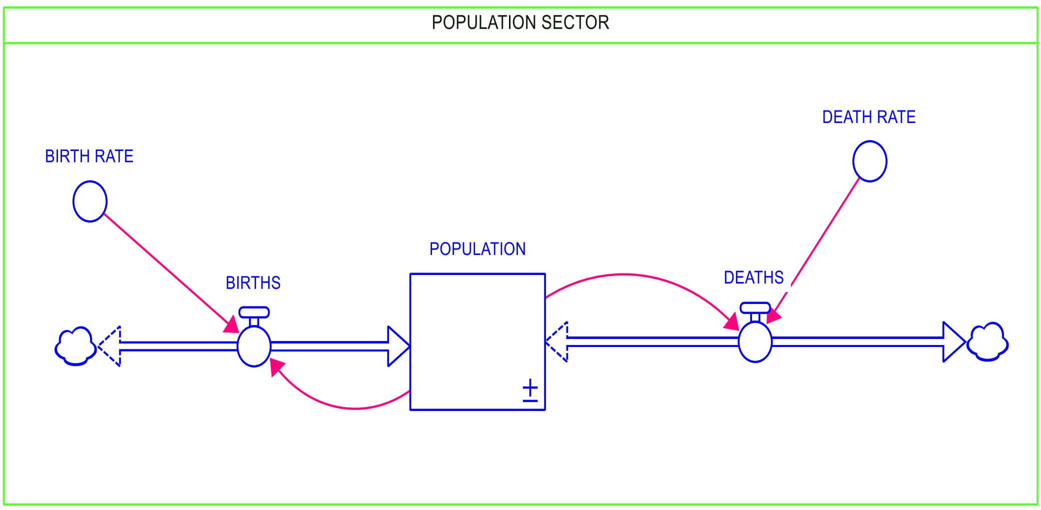



**Figure 3.10: Population Sector**

In this sector there is one stock which is population, and it is the total number of people in a given area. It has two flows namely: birth and death. Birth rate is the inflow which increases the stock population, and it is a function of population and birth rate. Birth rate represents the fraction of the population gives birth each year. The outflow death increases the stock population, and it is a function of the population and death rate. Death rate represents the fraction of the population that dies very year.

## 3.15 Modelling the Policy Sector

In this sector is where we have the policy that was implemented in the study.

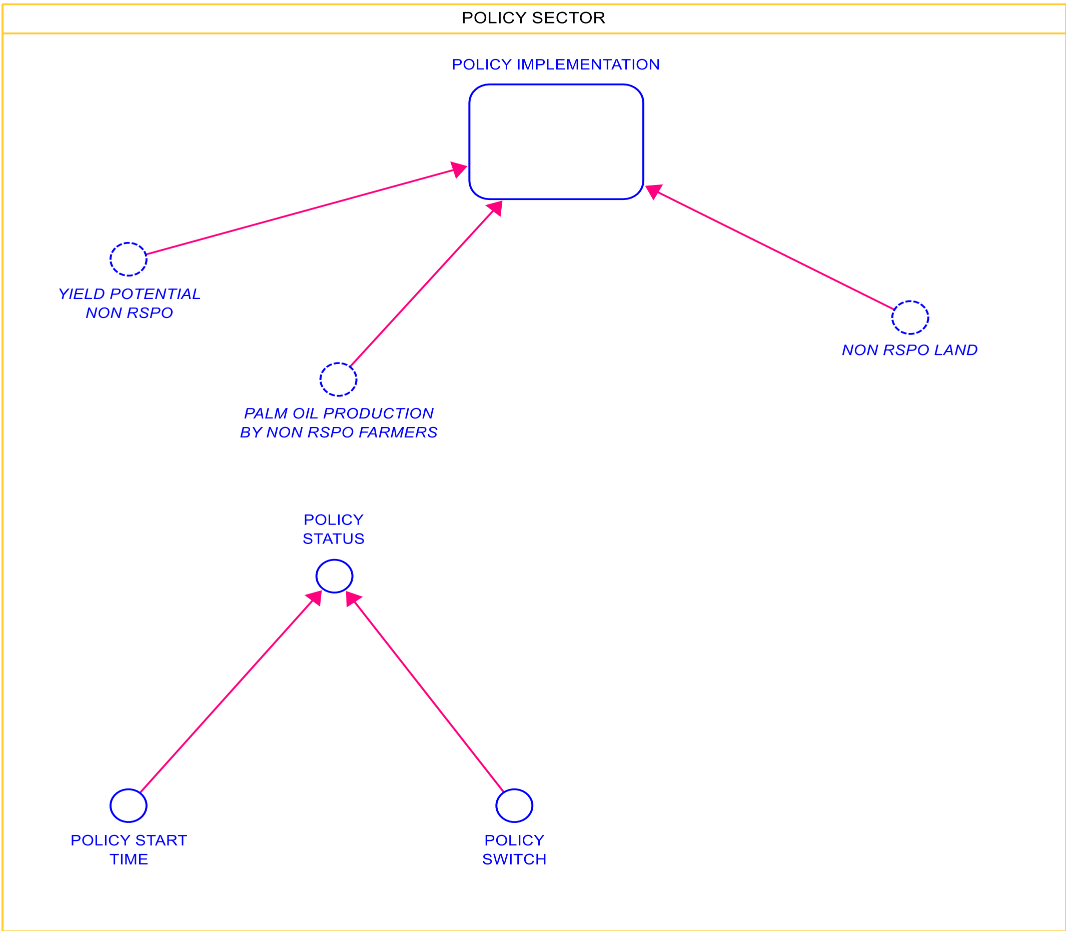



**Figure 3.11: Policy Implementation Sector**

The above structure is the policy implementation sector, this sector has the policy start time, policy switch, policy status and policy implementation. The other variables helped in this sector and an explanation has been given in their respective sector. Policy start time represents the year the policy is set to begin. Policy status represents the current state of the policy. Policy switches in the model plays a similar role as that of a normal switch. The policy switch changes the state of the policy that is whether it is being implemented or not.

### 3.16 Feedback Loops Descriptions (Causal Loop Diagrams, CLD)

Feedback loops are fundamental concepts that are used describing how system responds to changes. It describes how an action or event influences a system both negatively and positively. They help to explain behaviour of complex systems. It helps stakeholders gain insight in the way a system responds to changes overtime and use that to inform policy and interventions. A simplification of the model is done in the section of the study using causal loop diagram (CLD). In every CLD there two main major loops they are the balancing loop and reinforcing loop. In this section, causal loop diagram is used to explain the model.

**Causal Loop Diagram (CLD) 1**

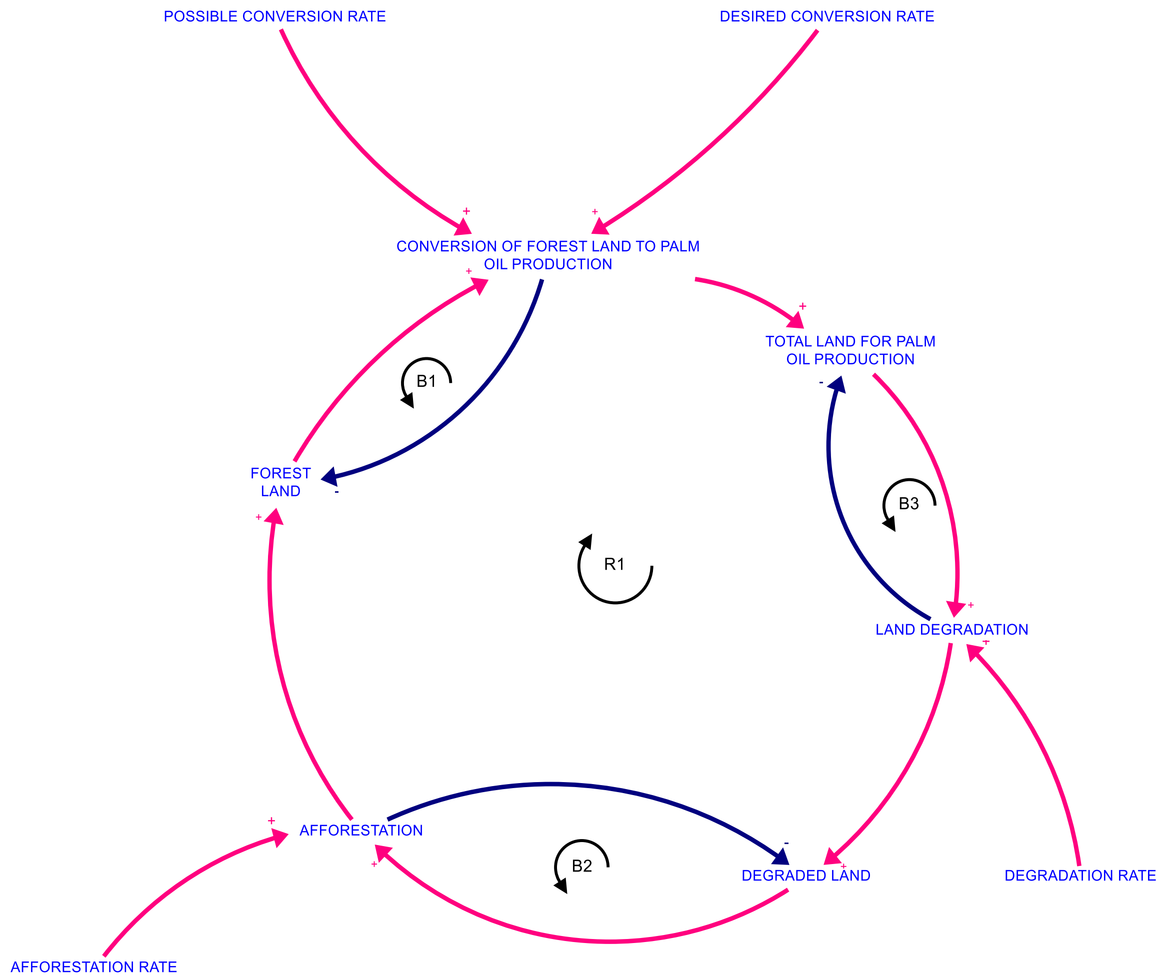



**Figure 3.12: Causal Loop Diagram 1**

In the above diagram we can see that there are plus and minus signs on the arrows, these are called the loop polarity.  The arrows seen in the diagram are the causal links. The pink arrow denotes a positive causal influence, and the blue denotes a negative causal influence.
As seen in the above diagram there is one reinforcing loop (R1) and three minor balancing loops (B1,B2,B3).

### 3.16.1 Balancing Loop 1

lancing loop, B1, illustrates the relationship between forest land and the conversion of forest land to palm oil production. It operates as follows:
When forest land increases, there is more land available for conversion into palm oil production. Consequently, the conversion of forest land to land for palm oil production increases. This positive causal link from forest land to the conversion of forest land to palm oil production indicates that as the amount of forest land expands, more land becomes available for palm oil production.
On the other hand, the higher the conversion of forest land to land for palm oil production, the lower the amount of forest land remaining. This negative causal link signifies that the process of converting forest land into land for palm oil production reduces the overall area of forest land. The first balancing loop demonstrates that an increase in forest land leads to more land available for conversion to palm oil production. Simultaneously, the conversion of forest land to palm oil production decreases the amount of forest land remaining. These interconnected feedback loops represent the dynamic relationship between forest land and its conversion to land for palm oil production.

### 3.16.2  Balancing Loop 2

The second balancing loop, B2, illustrates the relationship between afforestation and degraded land. It operates in a similar manner to B1, with a balancing feedback loop.
When there is an increase in degraded land, it creates a motivation to engage in afforestation activities. Afforestation involves planting trees and restoring vegetation in order to rehabilitate degraded areas. This positive causal link indicates that as the amount of degraded land increases, there is a corresponding increase in afforestation efforts.
Conversely, as afforestation activities increase, the amount of degraded land decreases. Afforestation helps in the restoration and recovery of degraded areas, leading to improvements

in land quality and a reduction in degraded land. The second balancing loop, B2, demonstrates that an increase in degraded land stimulates afforestation efforts. In turn, as afforestation increases, the extent of degraded land decreases. This interconnected feedback loop reflects the dynamic relationship between afforestation and the mitigation of degraded land.

### 3.16.3 Balancing Loop 3

The third balancing loop, B3, describes the relationship between land for palm oil production and degraded land. It follows a similar pattern as the previous balancing loops, with a reinforcing feedback loop.

When there is an increase in the total land designated for palm oil production, it leads to a higher level of degraded land. This positive causal link indicates that as more land is allocated for palm oil production, there is an associated increase in the extent of degraded land.

As degraded land increases, it creates a motivation to allocate more land for palm oil production. This positive causal link signifies that the presence of degraded land prompts the expansion of land specifically designated for palm oil production. The third balancing loop, B3, demonstrates that an increase in land for palm oil production contributes to an increase in degraded land. Simultaneously, the presence of degraded land acts as a driving force for the allocation of more land for palm oil production. These interconnected feedback loops represent the dynamic relationship between land for palm oil production and the extent of degraded land.

### 3.16.4 Reinforcing Loop 1

The reinforcing loop, R1, operates within this sector and is characterized by positive causal links that result in an amplifying effect. The logic behind this loop is that an increase in one variable leads to increases in other related variables, forming a reinforcing cycle. The causal links within this loop have positive polarity, indicating that an increase in one variable adds to the other variables connected to it.

In the case of R1, the loop begins with an increase in forest land. This increase in forest land leads to a subsequent increase in the conversion of forest land into palm oil production. As more forest land is converted, the total land designated for palm oil production also increases. This expansion of total land for palm oil production then contributes to an increase in land degradation. With increased land degradation, the extent of degraded land rises.

As degraded land increases, it creates a motivation for afforestation activities to rehabilitate and restore the land. Consequently, afforestation efforts increase, leading to the expansion of forest land once again. This positive feedback loop continues, as an increase in forest land stimulates further conversion to palm oil production, driving an increase in total land for palm oil production, land degradation, degraded land, and afforestation. The reinforcing loop, R1, within this sector demonstrates how an initial increase in forest land sets off a chain of positive feedback effects that result in the amplification of related variables, forming a reinforcing cycle.

**Causal Loop Diagram (CLD) 2**

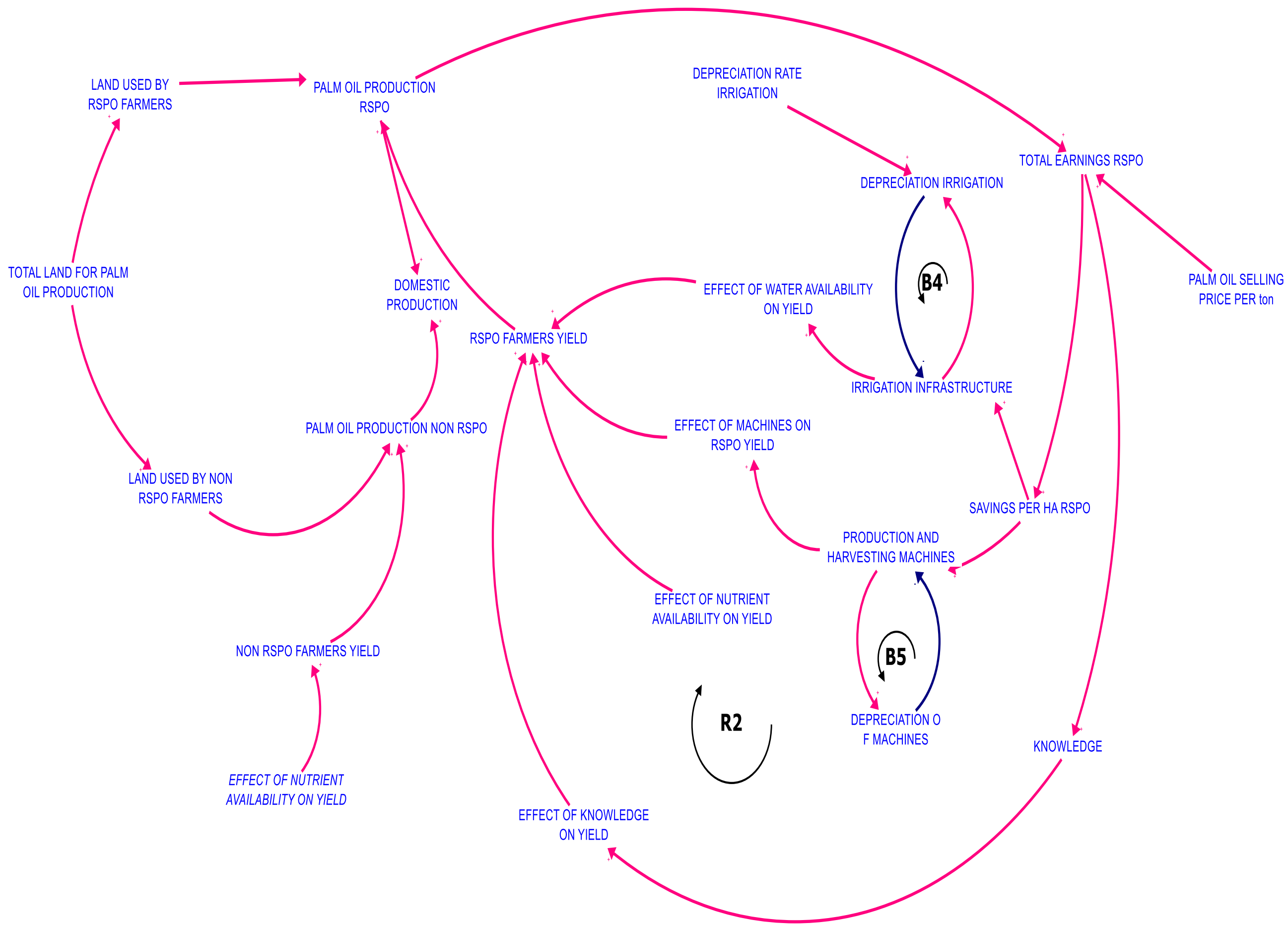



**Figure 3.13: Causal Loop Diagram 2**

This structure has three feedback loops. The description of the loops will start with B4, B5 and R2 respectively.

### 3.16.5 Balancing Loop 4

From the above CLD, the b4 is within the irrigation infrastructure. As mentioned previously, water is crucial for the growth of palm oil, and irrigation plays a significant role in meeting the water requirements during periods of low rainfall. The availability of water directly impacts the effectiveness of irrigation on yield. The more water farmers have access to, the greater the positive impact it will have on yield.

The irrigation sector serves as a supplementary source of water, particularly during dry seasons when rainfall is limited. It helps ensure that the water needs for palm oil cultivation are met, supporting optimal growth and productivity.

The B4 loop within the system dynamics diagram illustrates the relationship between irrigation infrastructure, water availability, and production. It demonstrates that an increase in irrigation infrastructure leads to a greater supply of water for farmers, which enables them to meet the production needs.

However, it is important to consider that infrastructure is subject to wear and tear over time. Depreciation sets in, causing a reduction in the effectiveness of irrigation infrastructure. This reduction in infrastructure capability is inevitable and can result in a decline in the availability of water for irrigation purposes. The B4 loop highlights the relationship between irrigation infrastructure, water availability, and production. It shows that an increase in irrigation infrastructure enhances water supply, supporting palm oil production. However, over time, the depreciation of infrastructure can lead to a decrease in water availability for irrigation, impacting production.

### 3.16.6 Balancing Loop 5

This loop is similar to balancing loop 4 (B4), pertains to the use of farming machinery and its impact on productivity. The use of farming machinery in agriculture improves productivity by reducing the physical effort required and saving time. This positive causal link indicates that as more machines are employed in farming, productivity increases. However, the use of machinery also leads to depreciation. Depreciation occurs as a result of wear and tear over time, reducing the effectiveness and lifespan of the machines. This negative causal link represents the decrease in machinery efficiency due to depreciation.

As the number of machines increases, the number of machines subject to depreciation also increases. This positive feedback loop demonstrates that a higher quantity of machines leads to more machinery experiencing depreciation. The loop illustrates that the use of farming machinery enhances productivity but is accompanied by the inevitable occurrence of depreciation. As more machines are utilized, the number of machines subject to depreciation increases. This interconnected feedback loop reflects the dynamic relationship between machinery usage, productivity, and the impact of depreciation on farming operations.

### 3.15.7 Reinforcing Loop 2

The reinforcing loop highlights the interconnected relationship between various factors that impact RSPO farmers' yield, income, irrigation infrastructure, production and harvesting machines, and knowledge. This reinforcing loop operates as follows:

An increase in production results in higher total earnings for RSPO farmers. As the total earnings increase, it provides the opportunity for investment and improvement in various sectors, including irrigation infrastructure, production and harvesting machines, and knowledge. The increase in irrigation infrastructure, production and harvesting machines, and knowledge enhances the effectiveness of these sectors. This positive causal link signifies that as these sectors improve, they contribute to an increase in yield.

As the yield increases, it leads to a further increase in production. This positive feedback loop creates a self-reinforcing cycle where an initial increase in production sets off a chain of positive effects that result in higher earnings, improved sectors, increased yield, and further production growth. Overall, this reinforcing loop demonstrates how an increase in production leads to higher earnings, which, in turn, enables investments in various sectors. The improvements in irrigation infrastructure, production and harvesting machines, and knowledge contribute to higher yield, driving further increases in production. This interconnected feedback loop emphasizes the dynamic relationship between production, earnings, sector improvements, and yield within the context of RSPO farmers.

# CHAPTER FOUR

## 4.1 Model Testing and Validation

Model testing and validation is an important aspect when building a system dynamic model. It helps in knowing the usefulness of a model, understanding the underlying structure; find out the robustness and sensitivity of the results according to the assumptions that were made with regards to the model boundary and interactions among variables. It helps build the confidence and the model's behaviour pattern and the results. According to Forrester (1973) and (Forrester and Senge, 1980), we "validate" the model by trying to build confidence in the soundness and usefulness of our model. The model built for this study was validated and tested. There are different types of validation and testing: parameter-confirmation test, structure assessment test, boundary adequacy test, structure-oriented behaviour test, face validity test and dimensional consistency test. According to Barlas (1996), a behavioral validity for a system dynamics model can be sufficient to ensure that the model is valid. Most parameter values used in the model are based on data estimates from the world data bank and research reports. An explaining of the validation and testing conducted in this study is given below.

## 4.2 Face validity testing

As the name implies, face validity tests ensure that by just looking at model structure it will be able to communicate and the model. The stocks and flows and converted used in building the model for this study have been assessed to ensure that they represent the system in real life. Looking at the stock inventory in the model and the flows, total production accumulates inventory and consumption reduces inventory. Consumption is based on the desired consumption which is derived from domestic consumption and palm oil exportation. Total production is derived from domestic production and palm oil importation which is a sum of the two. When this structure is assessed, it makes sense since it is logical for consumption and exportation to decrease and inventory and for domestic production and imported goods to increase your inventory.

## 4.3 Structure assessment test

Structure assessment tests are performed to determine whether the model is consistent with knowledge of a real system. It focuses on the level of aggressiveness and the model conformance to basic physical realities. (Sterman, 2000). This model was based on theoretical structure. According to Barlas (1996), direct structure tests assess how valid a model structure is by considering the relationship between variables including the equations used and comparing them to available knowledge on the system.

## 4.4 Parameter confirmation test

Variables and parameters used in the building of models for studies should be able to represent real life factors regarding the study. It confirms if the parameters in the structure are consistent with all relevant knowledge and ideology of the system. The parameters used in the model were based on the combination of current academic literature on the study and operational knowledge. Also, some parameters were based on data from the world data bank and research reports. Parameters that consistency were not able to be confirmed, calibrations and reasonable assumptions were used.

## 4.5 Dimensional consistency test

This test helps to detect whether there are false variables used in the model to help achieve dimensional consistency. Stellar unit and equation assistant check helps to check and ensure the consistency of all units in the model.

## 4.6 Boundary adequacy test

Boundary adequacy test is done to ensure that all the necessary structures or factors regarding the study are present in the model. One has to consider the objectives of the study and build a model that captures the study objective. In this study the main objective was to assess the RSPO scheme to see its impact on production. Some reasonable assumptions were made to the function effectively and also make it simple and ensuring its focus on the objectives. After analyzing the information and literature that guided the model building, the boundary of the model for this is deemed to be adequate. Thus, the model included the benefits farmers under the RSPO scheme received and how it helped with production. The model included feedback loops that exist among all the variables and parameters used.

## 4.7 Structure-oriented behavior test

According to Senge & Forrester (1980), structure behaviour tests are performed to check if the parameters are subjected to extreme values, they will still have a behaviour pattern that is similar to real life systems. The test was done by adjusting model parameters with high and low extreme values to determine whether the model equations made sense in these conditions and to see if computational errors such unit errors would be produced. Testing and observation revealed no defects; hence the structure model can be regarded as being sufficiently resilient under difficult circumstances.

# CHAPTER FIVE

## 5.1 Behaviour Analysis

In this chapter, we will examine the findings of the model simulation. The primary aim of the study is to investigate the influence of RSPO (Roundtable on Sustainable Palm Oil) on palm oil production specifically for small-scale farmers. To achieve this, a model was developed to illustrate the advantages received by RSPO farmers and how it affects their production. The results obtained from both RSPO farmers and non-RSPO farmers will now be analysed and compared. The objective is to determine whether RSPO certification has a positive impact on increasing the production of farmers who are part of the certification scheme.

## 5.2 Analysing major variables in both farming sectors.

The results of key variables among the RSPO sector and the non RSPO sector will be analysed in comparison to check level of each variable. The key variables to be analysed and compared are RSPO farmers yield and non RSPO farmers yield, total production RSPO farmers and total production non RSPO farmers, earnings RSPO farmers and earning of non RSPO farmers.

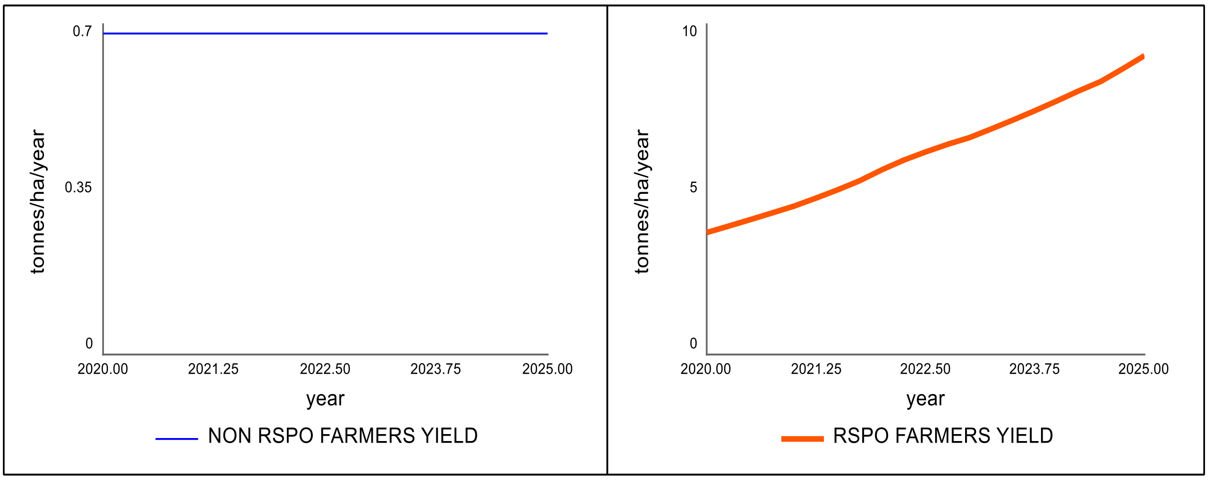



**Figure 5.1: Non RSPO farmers yield and RSPO farmers' yield.**

The analysis of the figures reveals significant differences in the yield between RSPO farmers and non-RSPO farmers. In the case of non-RSPO farmers, their yield remains constant at a value of 0.68 from 2020 throughout the simulation period. This stagnant yield can be attributed to the limited availability of resources and the absence of support that these farmers receive. They rely primarily on traditional farming methods, manual labour, and rainfall for cultivation. Studies have shown that the utilization of agricultural machinery contributes to land reclamation, minimizes soil erosion, enables efficient irrigation systems, and enhances productivity and crop yields, leading to increased income. However, non-RSPO small-scale farmers often lack access to high-yielding hybrid varieties and face funding constraints, which restricts their ability to invest in cultivation.

On the other hand, the second graph illustrates the yield of RSPO farmers, which demonstrates a steady increase over time. Starting at a value of 3.69 in 2020, the yield rises consistently to about 9.05 in 2025. As mentioned previously, higher yields contribute to increased production and subsequently lead to higher income for farmers. RSPO farmers benefit from the certification scheme, which provides various advantages to improve production. These benefits include access to farming machinery and irrigation sources, training and support from extension officers, improved seedlings with higher yields, and access to loans when needed. The utilization of improved seedlings is directly linked to higher yields, indicating that farmers under the RSPO certification scheme are likely to earn higher income compared to non-RSPO farmers.

The graph below shows the total production of RSPO farmers and the non RSPO farmers.

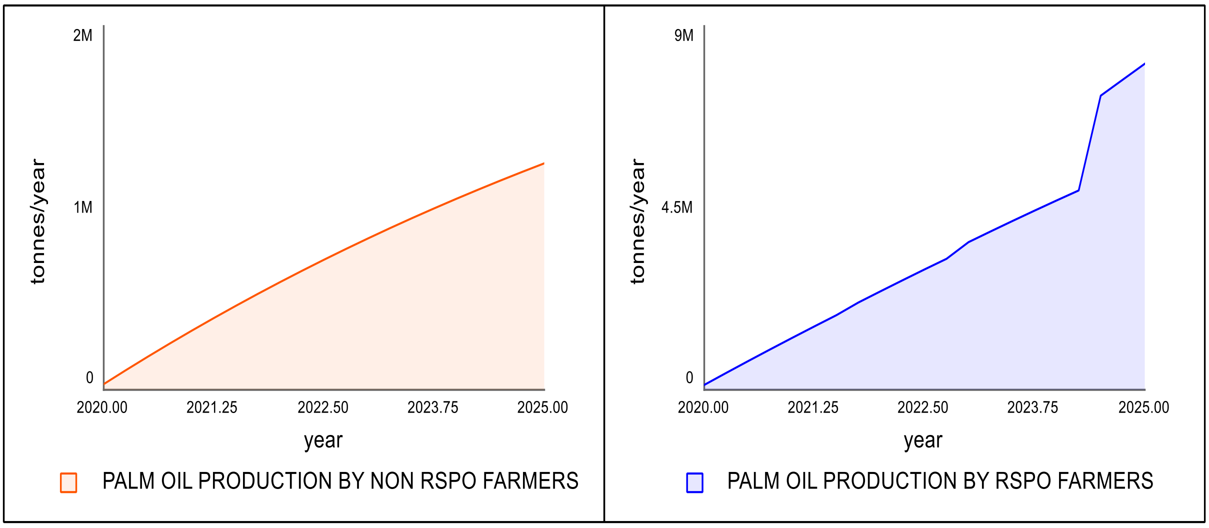



**Figure 5.2: Palm oil production of RSPO and non RSPO farmers.**

The graph presented above illustrates the combined production of RSPO farmers and non-RSPO farmers. RSPO farmers achieved a production volume of approximately 20 million tons, whereas non-RSPO farmers reached a little above million tons. Despite both groups experiencing an increase in production, it is evident that RSPO farmers had higher production values compared to non-RSPO farmers. Specifically, the production value of RSPO farmers was twice that of non-RSPO farmers on an annual basis. This increase in production can be attributed to a reinforcing loop (R2) wherein higher yields enable farmers to generate more income, thereby allowing them to invest more in irrigation infrastructure, training, production and harvesting machines, as well as fertilizers. The R2 loop indicates that as production increases, total earnings also increase, leading to higher savings for farmers who subsequently tend to invest more in irrigation, training, and farming machinery. The R2 loop's influence is evident in the areas of irrigation, training, and farming machinery. In the year 2020, RSPO farmers achieved a total production value of 170 thousand, while non-RSPO farmers recorded a value of 31thousand. It should be noted that the model assumed equal land sizes for both RSPO and non-RSPO farmers since there was no available data regarding the total land size of each group.

| | PALM OIL PRODUCTION BY NON RSPO FARMERS | PALM OIL PRODUCTION BY RSPO FARMERS |
|---|---|---|
| Initial | 31.3k | 170k |
| 2020 | 325k | 1.8M |
| 2021 | 592k | 3.46M |
| 2022 | 833k | 5.09M |
| 2023 | 1.05M | 6.91M |
| 2024 | 1.25M | 9.11M |

**Figure 5.3: RSPO farmers and non RSPO farmers production.**

The provided table displays the production values of both RSPO farmers and non-RSPO farmers. It is evident that RSPO farmers have a yield that is nearly three times higher than that of non-RSPO farmers.

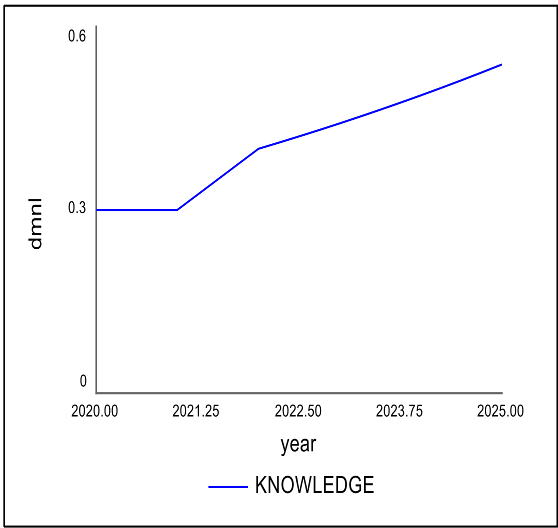

**Figure 5.4: RSPO farmers and non RSPO farmers income.**

The provided graph displays the income generated by both RSPO farmers and non-RSPO farmers over a six-year period, from 2020 to 2025. The graph exhibits an upward linear trend, indicating the cumulative nature of the variables. Figure 5.3 explains that the income of RSPO farmers shows a similar developmental pattern as their total production. Notably, the income of RSPO farmers is observed to be three times higher than that of non-RSPO farmers, primarily due to the lower yield of the non-RSPO group. In terms of numerical values, non-RSPO farmers earned a total income of 313 million GHS in 2020, while RSPO farmers achieved a significantly higher total income of 1.22 billion GHS.

| | TOTAL EARNINGS RSPO FARMERS | TOTAL EARNING NON RSPO |
|---|---|---|
| Initial | 1.22B | 313M |
| 2020 | 12.9B | 3.25B |
| 2021 | 24.4B | 5.92B |
| 2022 | 36.5B | 8.33B |
| 2023 | 46.9B | 10.5B |
| 2024 | 80.7B | 12.5B |

**Figure 5.5: RSPO farmers and non RSPO farmers income.**

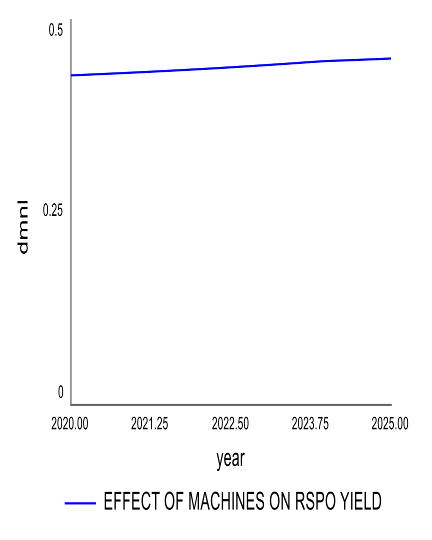
The table provided above displays the total earning of both RSPO farmers and non-RSPO farmers. It is evident that RSPO farmers have higher and it nearly over three times higher than that of non-RSPO farmers.




| | KNOWLEDGE | EFFECT OF KNOWLEDGE ON YIELD |
|---|---|---|
| Initial | 0.3 | 0.4 |
| 2020 | 0.3 | 0.4 |
| 2021 | 0.4 | 0.408 |
| 2022 | 0.442 | 0.426 |
| 2023 | 0.487 | 0.426 |
| 2024 | 0.538 | 0.599 |

**Figure 5.6: Effect of knowledge RSPO farmers' yield.**

Effect of knowledge on yield: This variable refers to the impact of knowledge and information on the yield or productivity of farmers. It recognizes that farmers who possess knowledge about modern farming techniques such as crop management practices, pest control, soil fertility, and other relevant factors are likely to achieve higher yields. In the above diagram it has been observed that higher knowledge in farming techniques will lead to a higher effect on yield. In the model simulation, this variable captures the understanding that education, training, and access to information play crucial roles in improving agricultural practices and ultimately enhancing crop productivity. From the table on the left we can see that when knowledge increased in year 2023, the effect on knowledge increased and an increase in effect of knowledge on yield in year 2024 when knowledge increased.

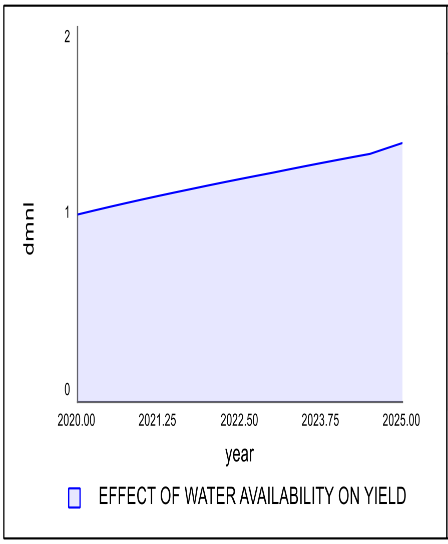



| | EFFECT OF MACHINES ON RSPO YIELD | PRODUCTION AND HARVESTING MACHINES |
|---|---|---|
| Initial | 0.428 | 100 |
| 2020 | 0.432 | 101 |
| 2021 | 0.436 | 102 |
| 2022 | 0.441 | 103 |
| 2023 | 0.447 | 104 |
| 2024 | 0.45 | 106 |

**Figure 5.7: Effect of machines RSPO farmers' yield.**

Effect of machines on farmers' yield: This variable represents the influence of utilizing agricultural machinery on farmers' yield. It acknowledges that the adoption and use of appropriate farming machinery, such as tractors, harvesters and irrigation systems can significantly contribute to increasing yield and overall productivity. By automating certain processes, reducing labour requirements, improving precision, and enhancing efficiency, machines enable farmers to optimize their operations and maximize their yield potential. From the table it is observed that the effect of machines on yield increases whenever there is an increase in production and harvesting machines when

Both of these variables highlight the interplay between external factors (knowledge and machines) and agricultural productivity. They emphasize that as access to knowledge and the use of appropriate machinery increases it can have an increasing impact on farmers' yields, leading to improved agricultural outcomes and potentially higher income for farmers.




| | EFFECT OF WATER AVAILABILITY ON YIELD | IRRIGATION INFRASTRUCTURE PER HA |
|---|---|---|
| Initial | 1 | 0 |
| 2020 | 1.08 | 520 |
| 2021 | 1.15 | 995 |
| 2022 | 1.22 | 1.44k |
| 2023 | 1.29 | 1.88k |
| 2024 | 1.38 | 2.46k |

**Figure 5.8: Effect of irrigation RSPO farmers' yield.**

The effect of irrigation on farmers' yield emphasizes the significant role irrigation plays in agricultural production. It points out that effective irrigation practices have several benefits for farmers, which include ensuring proper water supply. This practice contributes to optimizing plant growth, minimizing yield losses, and maintaining crop health. This implies that higher levels of irrigation positively impact crop yield. It suggests that when farmers provide sufficient water through irrigation, it enhances crop productivity and ultimately leads to higher yields. It also emphasizes that utilizing effective irrigation techniques can significantly influence the success of farming by promoting optimal conditions for plant growth and maximizing crop output. According to the results obtained, it has been observed that the effect of irrigation on yield continues increasing. This can be attributed to the fact that plants have specific water requirements for optimal growth and production. When the irrigation meets or closely matches these requirements, it provides the necessary moisture for the plants, leading to a consistent yield.

# CHAPTER SIX

## 6.1 Policy Design and Analysis

One of the key objectives of this study is to establish a policy model framework that can alter the trajectory of problematic behaviour in the future. While it is not possible to change the past, it is within our reach to shape the future. Policy design allows us to envision and bring about changes by improving the existing structure that underlies the historical problematic behaviour. This process involves more than just modifying values; it entails the complete creation of new structures, strategies, and decisions. In a system dynamic model, developing a policy model structure aims to identify and implement effective measures to address the challenges posed by the problematic behaviour. By analysing the historical dynamics and understanding the factors contributing to the problem, policymakers can devise strategies that facilitate positive change. These strategies may involve creating new policies, implementing novel approaches, and making informed decisions to shape a more desirable future.

The process of policy design is comprehensive and requires a holistic understanding of the problem at hand. It involves considering various aspects such as social, economic, and environmental factors, and integrating them into a cohesive framework. By developing new structures, strategies, and decisions, policymakers aim to alter the trajectory of the problematic behaviour and steer it towards a more favourable and sustainable future. This study developed a policy model structure to reshape the future by addressing the dynamics of problematic behaviour. This involves going beyond simply changing values and instead focuses on creating structures, strategies, and decisions to guide positive change and ensure a more desirable outcome. The policy design for this study is RSPO certification mechanisms that involves all small-scale farmers.

The policy sector consists of several structures, namely irrigation, knowledge structure, production and harvesting machines, and the revenue and expenditure sector. These structures are implemented within the policy sector with the specific aim of including non RSPO farmers and granting them access to the benefits associated with the RSPO certification scheme. Now, let's we will move to the explanation of the policy structure that was developed for this policy.

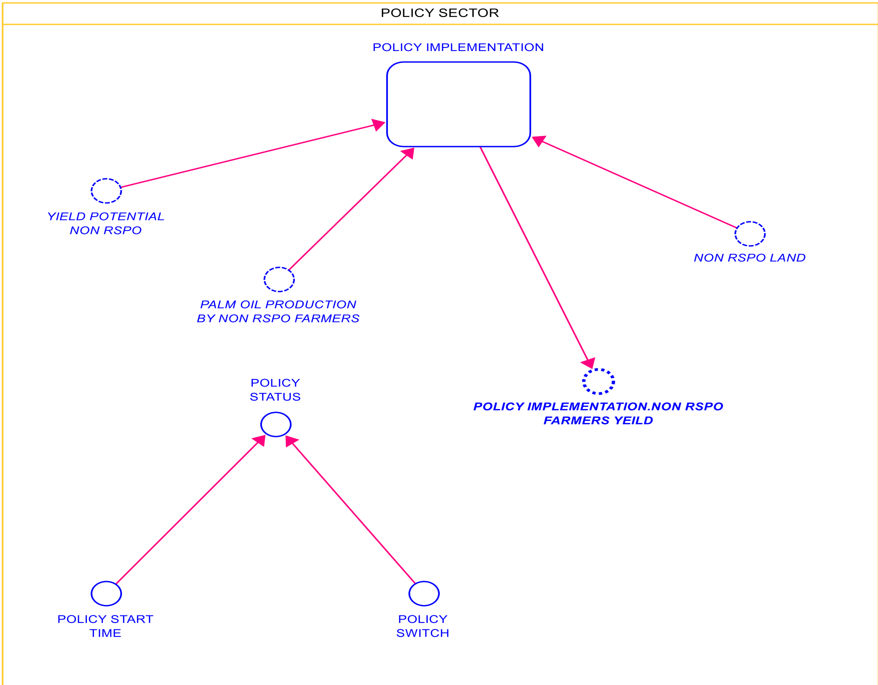



**Figure 6.1: Policy sector**

Upon analysing the behaviour of the model, it was observed that RSPO farmers tend to achieve higher yields compared to non RSPO farmers. This higher yield directly translates into increased income for RSPO farmers. Consequently, the decision to include non RSPO farmers aims to enhance their yield and subsequently boost their revenue. By including non RSPO farmers and improving their production values, there will be an overall increase in the inventory of palm oil. This increase in production is expected to meet the growing demand for palm oil in the market.

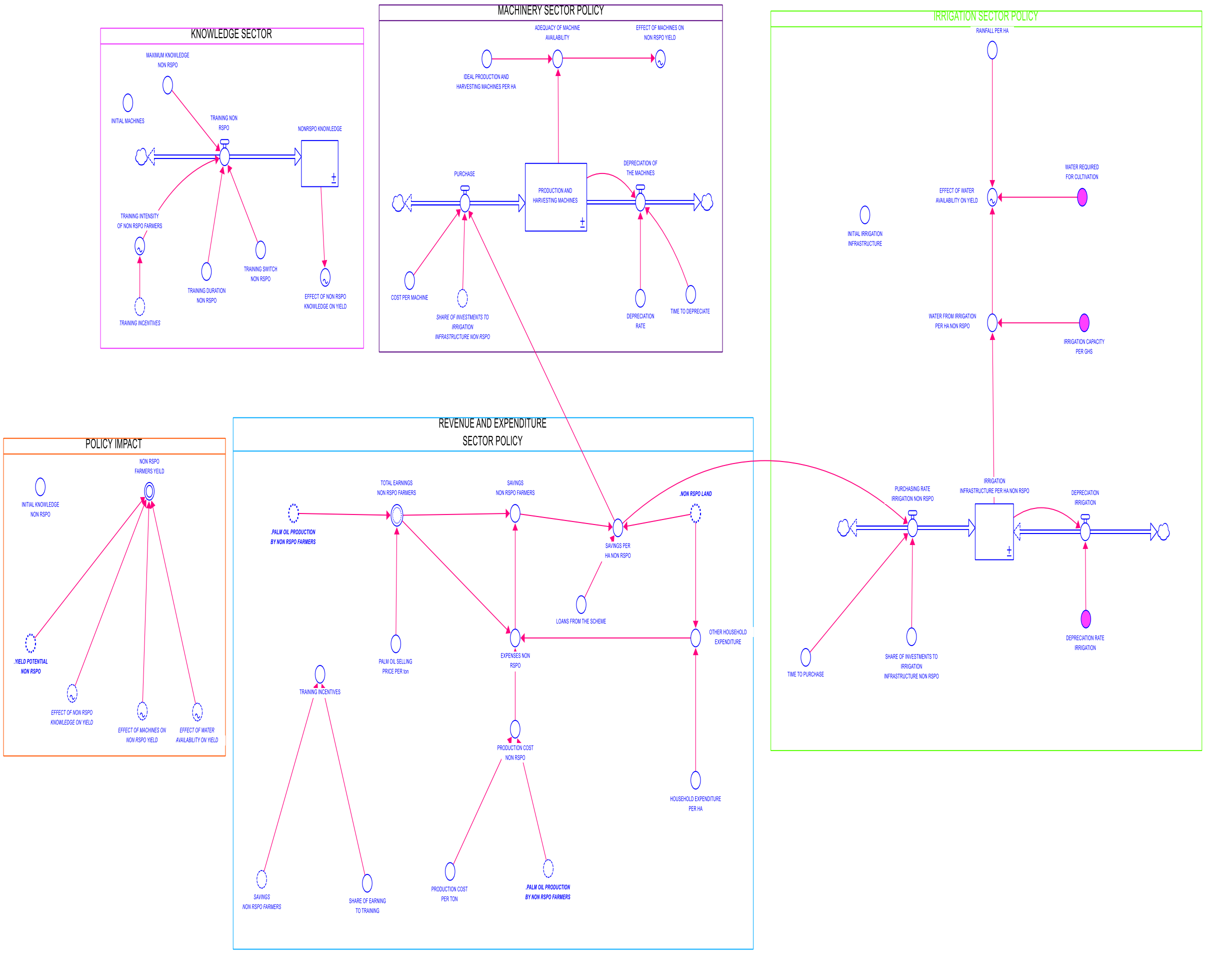



**Figure 6.2: Policy model**

The structure above is the policy structure with the various sectors and a clear picture of the various structure will be provided on the next page.

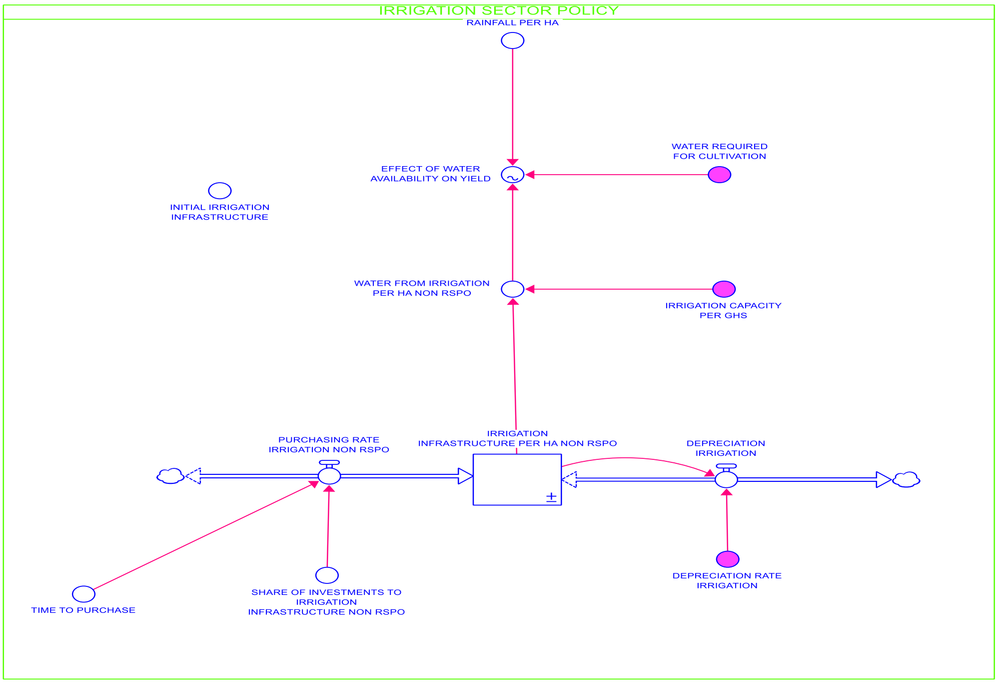



**Figure 6.3: Policy structure irrigation**

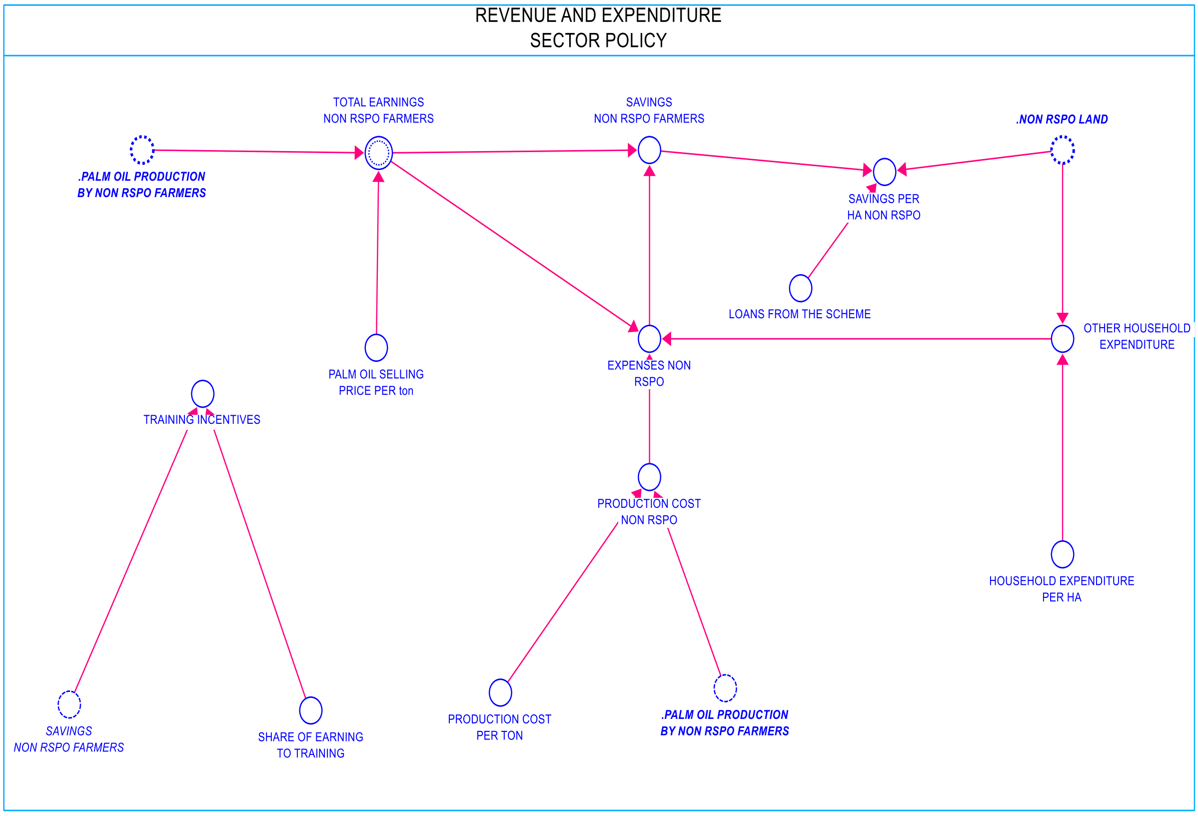



**Figure 6.4: Policy structure revenue and expenditure**

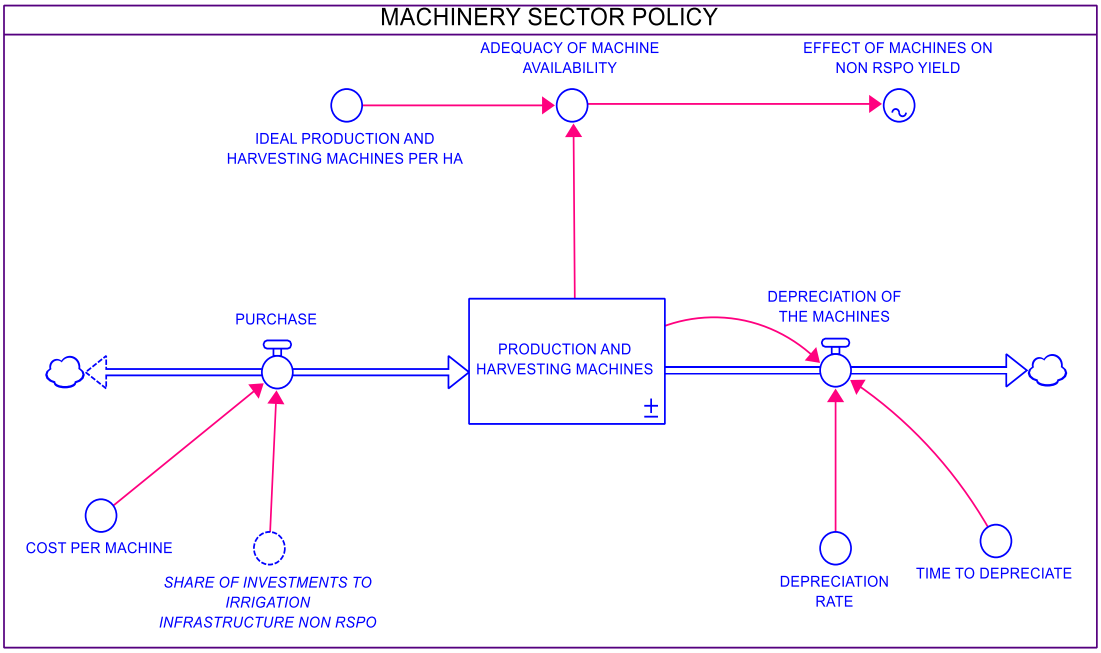



**Figure 6.5: Policy structure machinery**

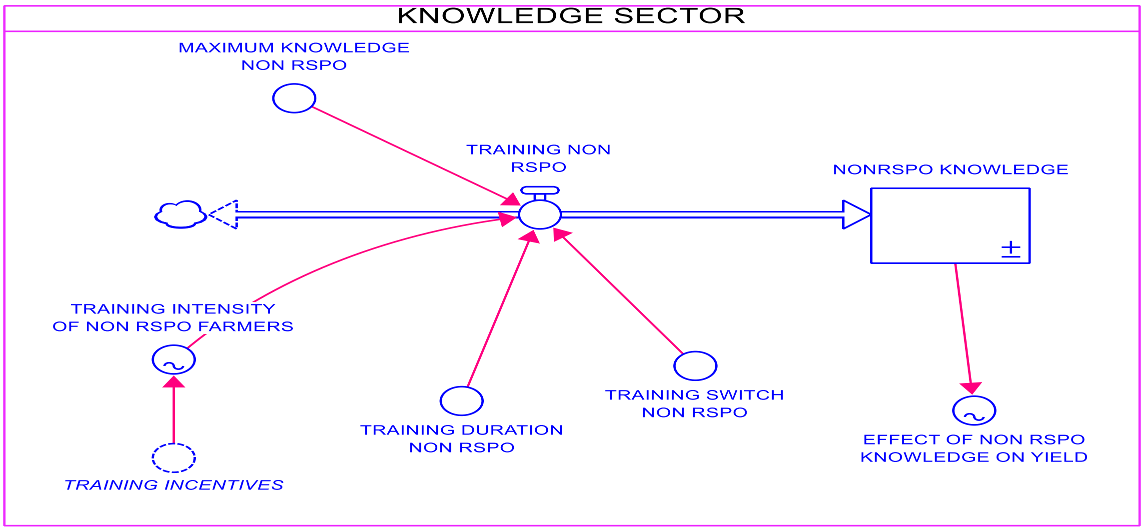



**Figure 6.6: Policy structure knowledge**

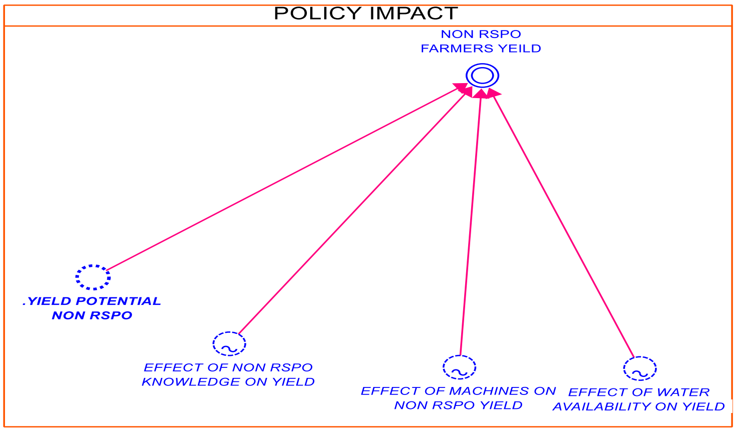



**Figure 6.7: Policy effect variables.**

The figures presented above depict the policy implementation structure, which bears resemblance to the previously explained structures in Chapter Three. These structures, such as irrigation, knowledge structure, production and harvesting machines, and the revenue and expenditure sector, are part of the policy sector designed for the simulation. Moving forward, the next topic of discussion revolves around the results obtained from the policy simulation.

## 6.2 Policy behavior Analysis

Results from the previous section have shown that farmers under the RSPO certification have higher yield compared to the farmers who are not under the certification program.

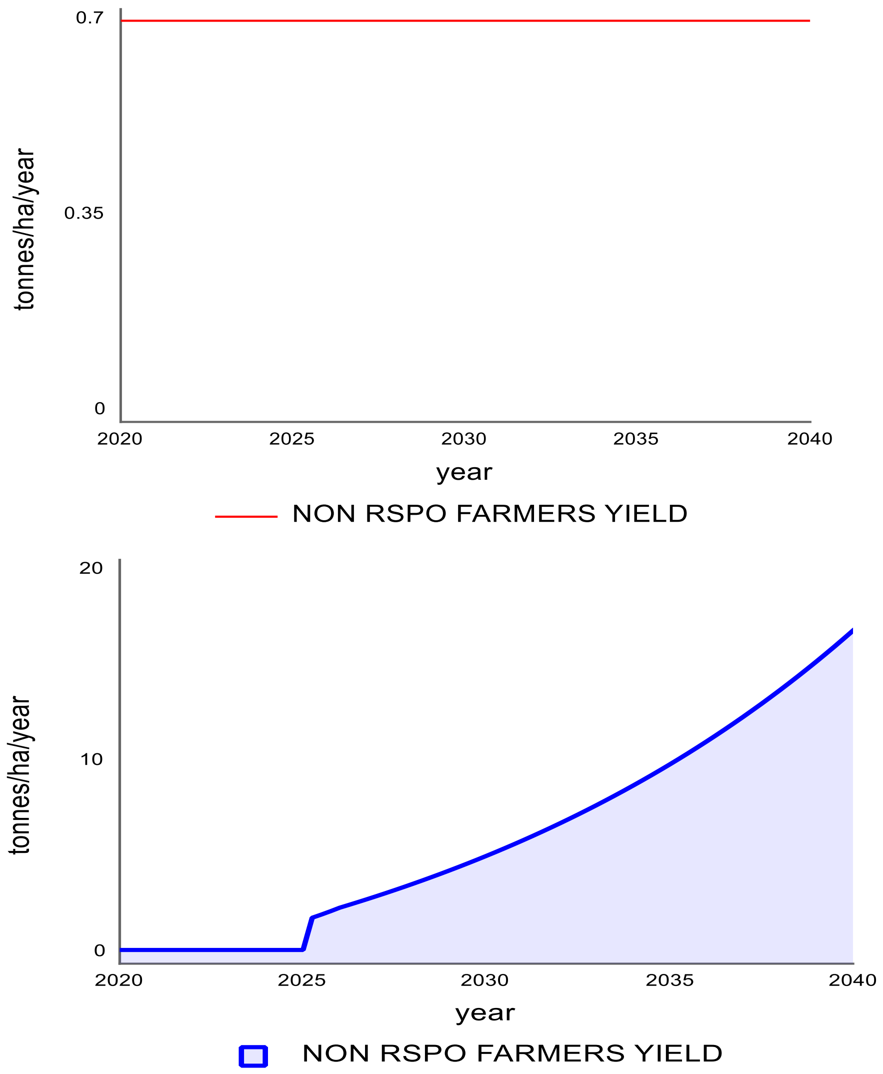



**Figure 6.8: non RSPO yield without and with policy.**

Based on the presented graph, it is evident that the introduction of the policy had a positive impact on the yield of non RSPO farmers. Yield holds significant importance in the field of agriculture, as it directly affects the quantity of harvest or produce.

The blue line in the graph represents the growth of non RSPO farmers without the policy. It appears to remain relatively constant at around 0.7, indicating a consistent yield level prior to the policy's implementation. However, the red line illustrates the yield of non RSPO farmers after the policy was introduced. It demonstrates a noticeable increase in yield, with values ranging from approximately 0.7 to 7. This increasing behaviour trend in yield indicates that the policy implementation positively influenced the productivity and output of non RSPO farmers.

This suggests that the policy measures implemented were effective in enhancing the yield of non RSPO farmers, ultimately leading to increased production and potentially higher economic gains for the farmers.

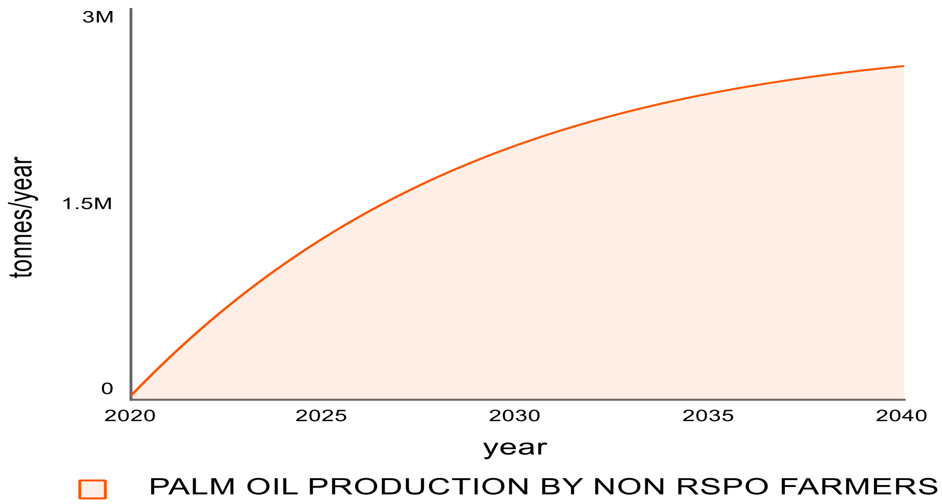



**Figure 6.9: non RSPO Production without policy.**

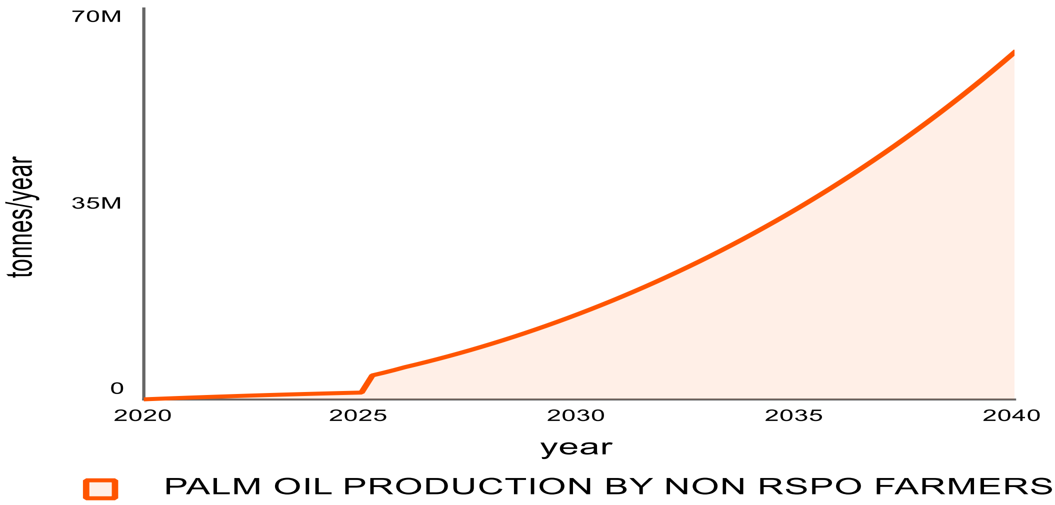



**Figure 6.10: non RSPO Production with policy.**

Before the policy was introduced, non RSPO production had a value of approximately 2 million. This relatively low production value could be attributed to various factors, including a lack of resources and other important factors necessary for efficient production. However, with the introduction of the policy and their participation in the certification program, the production of non RSPO farmers experienced a significant increase. The production value rose from around 2 million to 70 million.

This substantial growth can be attributed to the benefits and advantages they gained by joining the certification program. The policy likely provided non RSPO farmers with access to resources, knowledge, and support systems that were previously lacking. This enabled them to improve their production practices, enhance efficiency, and ultimately increase their overall production value. The benefits derived from the certification program played a crucial role in this positive transformation of their production capabilities.

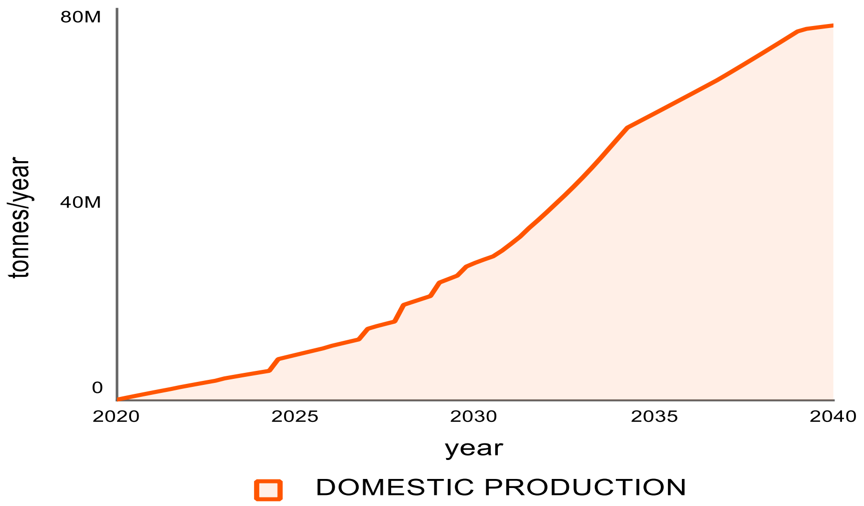



**Figure 6.11: Domestic Production without policy.**

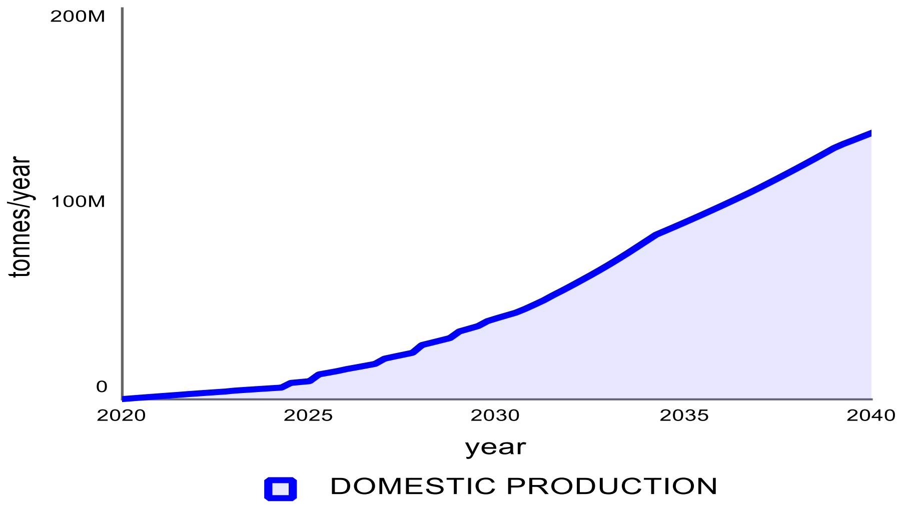



**Figure 6.12: Domestic with policy.**

Before the policy, domestic production was valued at 76 million, but after its introduction, there was an increase in domestic production.

It is observed that higher yield results in increased production, and as production increases, it leads to higher income. This higher income, in turn, enables increased investment in irrigation, water, and machines. The analysis suggests that when these sectors experience growth, it causes an increase in yields, leading to higher production and higher income. This pattern of interdependence is commonly referred to as a reinforcing loop, specifically reinforcing loop 2 in this context.

In reinforcing loop 2, an increase in one variable (such as investment in irrigation, water, and machines) leads to an increase in connected or related variables (yield, production, and income). This positive feedback loop reinforces the growth and development of the system.

From the above results it can be seen that the introduction of RSPO certification scheme to the farmers not registered brought a significant increase in domestic production. And as such farmers should be encouraged to join the certification scheme.

Based on the results obtained from this study, the introduction of the RSPO certification scheme to non-registered farmers has had a positive impact on domestic production. This indicates that the scheme has the potential to drive improvements in sustainability practices and increase production levels. Encouraging non-registered farmers to join the RSPO certification scheme can bring several benefits: The certification scheme, farmers can adopt sustainable practices that promote environmental conservation, responsible land use, and biodiversity protection. This can contribute to mitigating the negative impacts associated with palm oil production and ensure the long-term sustainability of the industry. Joining the RSPO certification scheme provides opportunities for training, knowledge sharing, and capacity building. Farmers can benefit from technical assistance and learn best practices from other certified producers. This can enhance their skills, productivity, and overall sustainability performance. Also, RSPO certification is recognized and preferred by many companies and consumers who are increasingly demanding sustainable palm oil. By joining the scheme, farmers gain access to a larger market and can attract buyers who prioritize sustainably produced palm oil. This can potentially lead to increased demand and better market prices for their products.

Overall, if the introduction of the RSPO certification scheme has led to a significant increase in domestic production, it suggests that encouraging non-registered farmers to join the scheme can be beneficial both for the farmers themselves and for promoting sustainable palm oil production as a whole.

# CHAPTER SEVEN

## 7.1 Conclusion

Based on the available information and reasonable assumptions, the RSPO certification scheme is considered beneficial to the agricultural sector, particularly in relation to the increasing demand for palm oil. The introduction of the RSPO has had a positive impact on the lives of many small-scale farmers and has influenced production practices. However, it is important to acknowledge that the conclusions drawn in this study are limited by the lack of actual data and the use of assumptions to fill those data gaps.

Despite these limitations, it is recommended that the RSPO certification scheme be promoted and enforced for better and more sustainable palm oil production. The RSPO's standards and principles aim to address environmental, social, and economic concerns associated with palm oil production. By adhering to these standards, palm oil producers can mitigate negative impacts on the environment and local communities, improve working conditions, and promote responsible land use practices.

## 7.2 Limitations

The primary limitation of this study is attributed to the lack of available data. Without sufficient data, it becomes challenging to make accurate and precise conclusions. The assumptions made in this study were based on reasonable estimations, but they may not fully reflect the reality of the situation. Therefore, it is important to consider these limitations when interpreting the findings of this study.

To overcome this limitation, future research should focus on gathering more comprehensive and reliable data to provide a more accurate assessment of the impact of the RSPO certification scheme on the agricultural sector. Additionally, conducting field studies and incorporating real-world data would help validate and strengthen the findings of this study.

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# APPENDIX

ACTUAL THESIS MODEL EQUATIONS

{ The model has 139 (139) variables (array expansion in parens).

In root model and 1 additional modules with 14 sectors.

Stocks: 11 (11) Flows: 17 (17) Converters: 111 (111)

Constants: 61 (61) Equations: 67 (67) Graphicals: 8 (8) }

Top-Level Model:

DEGRADED_LAND(t) = DEGRADED_LAND(t - dt) + (LAND_DEGRADATION - AFFORESTATION) * dt

INIT DEGRADED_LAND = 8400000

UNITS: ha

FOREST_LAND(t) = FOREST_LAND(t - dt) + (AFFORESTATION - CONVERSION_OF_FOREST_LAND_TO_PALM_OIL_PRODUCTION) * dt

INIT FOREST_LAND = 35100000

UNITS: ha

DOCUMENT: This stock represents the total forest cover in Ghana. And its estimated to be about 7.9 million ha.

https://www.statista.com/statistics/1153830/total-forest-area-in-ghana-in-square-kilometers/

IRRIGATION_INFRASTRUCTURE_PER_HA(t) = IRRIGATION_INFRASTRUCTURE_PER_HA(t - dt) + (PURCHASING_RATE_IRRIGATION - DEPRECIATION_IRRIGATION) * dt

INIT IRRIGATION_INFRASTRUCTURE_PER_HA = INITIAL_IRRIGATION_INFRASTRUCTURE

UNITS: ghs/hectares

KNOWLEDGE(t) = KNOWLEDGE(t - dt) + (TRAINING) * dt

INIT KNOWLEDGE = INITIAL_KNOWLEDGE

UNITS: dmnl

PALM_OIL_INVENTORY(t) = PALM_OIL_INVENTORY(t - dt) + (TOTAL_PRODUCTION - CONSUMPTION) * dt

INIT PALM_OIL_INVENTORY = 1

UNITS: tonnes

POPULATION(t) = POPULATION(t - dt) + (BIRTHS - DEATHS) * dt

INIT POPULATION = 32180000

UNITS: person

PRODUCTION_AND_HARVESTING_MACHINES(t) = PRODUCTION_AND_HARVESTING_MACHINES(t - dt) + (PURCHASE - DEPRECIATION_OF_THE_MACHINES) * dt

INIT PRODUCTION_AND_HARVESTING_MACHINES = INITIAL_MACHINES

UNITS: machines/ha

TOTAL_LAND_FOR_PALM_OIL_PRODUCTION(t) = TOTAL_LAND_FOR_PALM_OIL_PRODUCTION(t - dt) + (CONVERSION_OF_FOREST_LAND_TO_PALM_OIL_PRODUCTION - LAND_DEGRADATION) * dt

INIT TOTAL_LAND_FOR_PALM_OIL_PRODUCTION = 360000

UNITS: ha

AFFORESTATION = DEGRADED_LAND*AFFORESTATION_RATE

UNITS: ha/year

BIRTHS = POPULATION*BIRTH_RATE

UNITS: person/year

CONSUMPTION = MIN(DESIRED_CONSUMPTION, POSSIBLE_CONSUMPTION)

UNITS: tonnes/year

CONVERSION_OF_FOREST_LAND_TO_PALM_OIL_PRODUCTION = MIN(DESIRED_CONVERSION_RATE, POSSIBLE_CONVERSION_RATE)

UNITS: ha/year

DEATHS = POPULATION*DEATH_RATE

UNITS: person/year

DEPRECIATION_IRRIGATION = IRRIGATION_INFRASTRUCTURE_PER_HA*DEPRECIATION_RATE_IRRIGATION

UNITS: ghs/(Hectares*Years)

DEPRECIATION_OF_THE_MACHINES = PRODUCTION_AND_HARVESTING_MACHINES*DEPRECIATION_RATE/TIME_TO_DEPRECIATE {UNIFLOW}

UNITS: machines/ha/year

LAND_DEGRADATION = TOTAL_LAND_FOR_PALM_OIL_PRODUCTION*DEGRADATION_RATE

UNITS: ha/year

PURCHASE = (SAVINGS_PER_HA_RSPO*SHARE_OF_INVESTMENTS_TO_MACHINES_AND_IRRIGATION_INFRASTRUCTURE)/COST_PER_MACHINE

UNITS: machines/ha/year

PURCHASING_RATE_IRRIGATION = SAVINGS_PER_HA_RSPO*SHARE_OF_INVESTMENTS_TO_MACHINES_AND_IRRIGATION_INFRASTRUCTURE/TIME_TO_PURCHASE

UNITS: ghs/(Hectares*Years)

TOTAL_PRODUCTION = PALM_OIL_IMPORTATION+DOMESTIC_PRODUCTION

UNITS: tonnes/year

TRAINING =
TRAINING_SWITCH*STEP(TRAINING_INTENSITY_OF_RSPO_FARMERS, 2021)-
STEP(TRAINING_INTENSITY_OF_RSPO_FARMERS,
2021+TRAINING_DURATION)*(MAXIMUM_KNOWLEDGE-KNOWLEDGE)
{UNIFLOW}

UNITS: dmnl/year

ADEQUACY_OF_MACHINE_AVAILABILITY =
PRODUCTION_AND_HARVESTING_MACHINES/IDEAL_PRODUCTION_AND_HAR
VESTING_MACHINES_PER_HA

UNITS: machines/machine

AFFORESTATION_RATE = 0.1

UNITS: dmnl/year

AVERAGE_YIELD =
RSPO_FARMERS_YIELD*FRACTION_USED_BY_FARMERS+NON_RSPO_FARMERS
_YIELD*(1-FRACTION_USED_BY_FARMERS)

UNITS: tonnes/ha/year

BIRTH_RATE = 0.03

UNITS: dmnl/year

COST_PER_MACHINE = 5000

UNITS: ghs/machine

CULTIVATION_RATE = 0.8

UNITS: dmnl

DEATH_RATE = 0.007

UNITS: dmnl/year

DEGRADATION_RATE = 0.02

UNITS: dmnl/year

DEPRECIATION_RATE = 0.015

UNITS: dmnl/year

DEPRECIATION_RATE_IRRIGATION = 0.2

UNITS: dmnl/year

DESIRED_CONSUMPTION =
DOMESTIC_CONSUMPTION+PALM_OIL_EXPORTATION

UNITS: tonnes/year

DESIRED_CONVERSION_RATE =
MAX(DESIRED_LAND_FOR_PALM_OIL_PRODUCTION-
TOTAL_LAND_FOR_PALM_OIL_PRODUCTION,
0)/TIME_TO_CONVERT_FOREST_INTO_PALM_OIL_LAND

UNITS: ha/year

DESIRED_LAND_FOR_PALM_OIL_PRODUCTION =
DESIRED_CONSUMPTION/AVERAGE_YIELD

UNITS: ha

DOMESTIC_CONSUMPTION =
PALM_OIL_CONSUMPTION_PER_CAPITA*POPULATION

UNITS: tonnes/year

DOMESTIC_PRODUCTION =
PALM_OIL_PRODUCTION_BY_NON_RSPO_FARMERS+PALM_OIL_PRODUCTION_
BY_RSPO_FARMERS

UNITS: tonnes/year

EFFECT_OF_KNOWLEDGE_ON_YIELD = GRAPH(KNOWLEDGE)

Points: (0.3000, 0.400), (0.3700, 0.4076), (0.4400, 0.426), (0.5100, 0.599), (0.5800, 0.606), (0.6500, 0.700), (0.7200, 0.8394), (0.7900, 0.9301), (0.8600, 0.974), (0.9300, 0.9924), (1.0000, 1.000) {GF DISCRETE}

UNITS: dmnl

EFFECT_OF_MACHINES_ON_RSPO_YIELD = GRAPH(ADEQUACY_OF_MACHINE_AVAILABILITY)

Points: (10.0, 0.140), (24.0, 0.2651), (38.0, 0.3174), (52.0, 0.4466), (66.0, 0.507), (80.0, 0.800), (94.0, 0.893), (108.0, 0.9994), (122.0, 0.9996), (136.0, 0.9999), (150.0, 1.000)

UNITS: dmnl

EFFECT_OF_NUTRIENT_AVAILABILITY_ON_YIELD = GRAPH(NUTRIENTS_AVAILABLE/NUTRIENTS_NEEDED_FOR_CULTIVATION)

Points: (0.000, 0.000), (0.100, 0.1505), (0.200, 0.2868), (0.300, 0.410), (0.400, 0.5215), (0.500, 0.6225), (0.600, 0.7138), (0.700, 0.7964), (0.800, 0.8711), (0.900, 0.9388), (1.000, 1.000)

UNITS: dmnl

EFFECT_OF_WATER_AVAILABILITY_ON_YIELD = GRAPH((RAINFALL_PER_HA+WATER_FROM_IRRIGATION_PER_HA)/WATER_REQUIRED_FOR_CULTIVATION)

Points: (0.000, 0.000), (0.200, 0.02526), (0.400, 0.08682), (0.600, 0.2331), (0.800, 0.5352), (1.000, 1.000), (1.200, 1.465), (1.400, 1.767), (1.600, 1.913), (1.800, 1.975), (2.000, 2.000)

UNITS: dmnl

EXPENSES_RSPO = MIN(TOTAL_EARNINGS_RSPO_FARMERS, OTHER_HOUSEHOLD_EXPENDITURE+PRODUCTION_COST_RSPO)

UNITS: ghs/year

FERTILIZERS = 243.7

UNITS: mg/kg/year

FRACTION_USED_BY_FARMERS = 0.16

UNITS: dmnl

DOCUMENT: This represents the proportion land that is used by  farmers

HOUSEHOLD_EXPENDITURE_PER_HA = 1000

UNITS: ghs/ha/year

IDEAL_PRODUCTION_AND_HARVESTING_MACHINES_PER_HA = 2

UNITS: machine/ha

INITIAL_IRRIGATION_INFRASTRUCTURE = 4000

UNITS: ghs/hectares

INITIAL_KNOWLEDGE = 0.3

UNITS: dmnl

INITIAL_MACHINES = 100

UNITS: machines/ha

IRRIGATION_CAPACITY_PER_GHS = 0.1

UNITS: Hectares*Millimeters/(ghs*Years)

LAND_USED_BY_RSPO_FARMERS = TOTAL_LAND_FOR_PALM_OIL_PRODUCTION*CULTIVATION_RATE*FRACTION_USED_BY_FARMERS

UNITS: ha

DOCUMENT: The total land used the RSPO farmers.

MAXIMUM_KNOWLEDGE = 1

UNITS: dmnl

NATURAL_FERTILIZERS = NUTRIENTS_FROM_PLANTS+NUTRIENTS_FROM_ANIMAL

UNITS: mg/kg/year

NON_RSPO_FARMERS_YIELD = IF(POLICY_STATUS=0) THEN(YIELD_POTENTIAL_NON_RSPO*EFFECT_OF_NUTRIENT_AVAILABILITY_ON_YIELD)ELSE(POLICY_IMPLEMENTATION.NON_RSPO_FARMERS_YEILD)

UNITS: tonnes/ha/year

NON_RSPO_LAND =
TOTAL_LAND_FOR_PALM_OIL_PRODUCTION*CULTIVATION_RATE*FRACTION_USED_BY_FARMERS

UNITS: ha

NUTRIENTS_AVAILABLE = NATURAL_FERTILIZERS+FERTILIZERS

UNITS: mg/kg/year

NUTRIENTS_FROM_ANIMAL = 243.7

UNITS: mg/kg/year

NUTRIENTS_FROM_PLANTS = 243.7

UNITS: mg/kg/year

NUTRIENTS_NEEDED_FOR_CULTIVATION = 1000

UNITS: mm

OTHER_HOUSEHOLD_EXPENDITURE =
LAND_USED_BY_RSPO_FARMERS*HOUSEHOLD_EXPENDITURE_PER_HA

UNITS: ghs/year

PALM_OIL_CONSUMPTION_PER_CAPITA = 496040.5

UNITS: tonnes/person/year

PALM_OIL_EXPORTATION = 63934108

UNITS: tonnes/year

PALM_OIL_IMPORTATION = 316363604

UNITS: tonnes/year

PALM_OIL_PRODUCTION_BY_NON_RSPO_FARMERS =
NON_RSPO_FARMERS_YIELD*NON_RSPO_LAND

UNITS: tonnes/year

PALM_OIL_PRODUCTION_BY_RSPO_FARMERS =
LAND_USED_BY_RSPO_FARMERS*RSPO_FARMERS_YIELD

UNITS: tonnes/year

PALM_OIL_SELLING_PRICE_PER_ton = 10000

UNITS: ghs/tonnes

POLICY_START_TIME = 2025

UNITS: year

POLICY_STATUS =
IF(POLICY_SWITCH=1)AND(POLICY_START_TIME<TIME)THEN(1)ELSE(0)

UNITS: dmnl

POLICY_SWITCH = 0

UNITS: dmnl

POSSIBLE_CONSUMPTION = PALM_OIL_INVENTORY/TIME_TO_CONSUME

UNITS: tonnes/year

POSSIBLE_CONVERSION_RATE =
FOREST_LAND/TIME_TO_CONVERT_FOREST_INTO_PALM_OIL_LAND

UNITS: ha/year

PRODUCTION_COST_PER_TON = 3000

UNITS: ghs/tonne

PRODUCTION_COST_RSPO =
PALM_OIL_PRODUCTION_BY_RSPO_FARMERS*PRODUCTION_COST_PER_TON

UNITS: ghs/year

RAINFALL_PER_HA = 1500

UNITS: mm/year

RSPO_FARMERS_YIELD =
(YIELD_POTENTIAL_RSPO*EFFECT_OF_WATER_AVAILABILITY_ON_YIELD*EFFECT_OF_NUTRIENT_AVAILABILITY_ON_YIELD*EFFECT_OF_KNOWLEDGE_ON_YIELD*EFFECT_OF_MACHINES_ON_RSPO_YIELD)

UNITS: tonnes/ha/year

DOCUMENT: This variable refers to the average yield per hectare of the land used by RSPO farmers.

SAVINGS_PER_HA_RSPO = SAVINGS_RSPO_FARMERS/LAND_USED_BY_RSPO_FARMERS

UNITS: ghs/(Hectares*Year)

SAVINGS_RSPO_FARMERS = TOTAL_EARNINGS_RSPO_FARMERS-EXPENSES_RSPO

UNITS: ghs/year

SHARE_OF_EARNING_TO_TRAINING = 0.0001

UNITS: dmnl

SHARE_OF_INVESTMENTS_TO_MACHINES_AND_IRRIGATION_INFRASTRUCTURE = 0.5

UNITS: dmnl

TIME_TO_CONSUME = 1

UNITS: year

TIME_TO_CONVERT_FOREST_INTO_PALM_OIL_LAND = 10

UNITS: year

DOCUMENT:

Tiemen Rhebergen, Thomas Fairhurst, Shamie Zingore, Myles Fisher, Thomas Oberthür, Anthony Whitbread,

Climate, soil and land-use based land suitability evaluation for oil palm production in Ghana,

European Journal of Agronomy,

Volume 81,

2016,

Pages 1-14,

ISSN 1161-0301,

https://doi.org/10.1016/j.eja.2016.08.004

TIME_TO_DEPRECIATE = 5

UNITS: dmnl

TIME_TO_PURCHASE = 10

UNITS: dmnl

TOTAL_EARNING_NON_RSPO = PALM_OIL_PRODUCTION_BY_NON_RSPO_FARMERS*PALM_OIL_SELLING_PRICE_PER_ton

UNITS: ghs/year

TOTAL_EARNINGS_RSPO_FARMERS = PALM_OIL_SELLING_PRICE_PER_ton*PALM_OIL_PRODUCTION_BY_RSPO_FARMERS

UNITS: ghs/year

TOTAL_LAND_AREA = 22753300

UNITS: ha

DOCUMENT: This is the total land area and it has been converted from km to hectare.

TRAINING_DURATION = 1

UNITS: year

TRAINING_INCENTIVES = SHARE_OF_EARNING_TO_TRAINING*SAVINGS_RSPO_FARMERS

UNITS: ghs/year

TRAINING_INTENSITY_OF_RSPO_FARMERS = GRAPH(TRAINING_INCENTIVES)

Points: (30.00, 0), (32.00, 0.001263), (34.00, 0.004341), (36.00, 0.01165), (38.00, 0.02676), (40.00, 0.05), (42.00, 0.07324), (44.00, 0.08835), (46.00, 0.09566), (48.00, 0.09874), (50.00, 0.1)

UNITS: dmnl/year

TRAINING_SWITCH = 1

UNITS: dmnl

WATER_FROM_IRRIGATION_PER_HA = IRRIGATION_INFRASTRUCTURE_PER_HA*IRRIGATION_CAPACITY_PER_GHS

UNITS: Millimeters/Years

WATER_REQUIRED_FOR_CULTIVATION = 1500

UNITS: mm/year

YIELD_POTENTIAL_NON_RSPO = 0.83

UNITS: tonnes/ha/year

DOCUMENT: https://ipad.fas.usda.gov/highlights/2022/09/Ghana/index.pdf

YIELD_POTENTIAL_RSPO = 4*3

UNITS: tonnes/ha/year

DOCUMENT: this refers to the maximum achievable yield under optimal growing.

=average yield*3

https://rspo.org/ghanaian-farmers-become-countrys-first-certified-rspo-independent-smallholder-group/

POLICY_IMPLEMENTATION:

IRRIGATION_INFRASTRUCTURE_PER_HA_NON_RSPO(t) = IRRIGATION_INFRASTRUCTURE_PER_HA_NON_RSPO(t - dt) + (PURCHASING_RATE_IRRIGATION_NON_RSPO - DEPRECIATION_IRRIGATION) * dt

INIT IRRIGATION_INFRASTRUCTURE_PER_HA_NON_RSPO = 0

UNITS: ghs/hectares

NONRSPO_KNOWLEDGE(t) = NONRSPO_KNOWLEDGE(t - dt) + (TRAINING_NON_RSPO) * dt

INIT NONRSPO_KNOWLEDGE = 0.6

UNITS: dmnl/year

PRODUCTION_AND_HARVESTING_MACHINES(t) = PRODUCTION_AND_HARVESTING_MACHINES(t - dt) + (PURCHASE - DEPRECIATION_OF_THE_MACHINES) * dt

INIT PRODUCTION_AND_HARVESTING_MACHINES = INITIAL_MACHINES

UNITS: machines/ha

DEPRECIATION_IRRIGATION = IRRIGATION_INFRASTRUCTURE_PER_HA_NON_RSPO*DEPRECIATION_RATE_IRRIGATION

UNITS: ghs/(Hectares*Years)

DEPRECIATION_OF_THE_MACHINES =
(PRODUCTION_AND_HARVESTING_MACHINES*DEPRECIATION_RATE)/TIME_TO_DEPRECIATE {UNIFLOW}

UNITS: machines/ha/year

PURCHASE =
(SAVINGS_PER_HA_NON_RSPO*SHARE_OF_INVESTMENTS_TO_IRRIGATION_INFRASTRUCTURE_NON_RSPO/COST_PER_MACHINE)

UNITS: machines/ha/year

PURCHASING_RATE_IRRIGATION_NON_RSPO =
(SAVINGS_PER_HA_NON_RSPO*SHARE_OF_INVESTMENTS_TO_IRRIGATION_INFRASTRUCTURE_NON_RSPO)/TIME_TO_PURCHASE

UNITS: ghs/(Hectares*Years)

TRAINING_NON_RSPO =
TRAINING_SWITCH_NON_RSPO*STEP(TRAINING_INTENSITY_OF_NON_RSPO_FARMERS,2025)-STEP(TRAINING_INTENSITY_OF_NON_RSPO_FARMERS, 2025+TRAINING_DURATION_NON_RSPO)*(MAXIMUM_KNOWLEDGE_NON_RSPO)

UNITS: dmnl/year/year

ADEQUACY_OF_MACHINE_AVAILABILITY =
PRODUCTION_AND_HARVESTING_MACHINES/IDEAL_PRODUCTION_AND_HARVESTING_MACHINES_PER_HA

UNITS: machines/machine

COST_PER_MACHINE = 5000

UNITS: ghs/machine

DEPRECIATION_RATE = 0.015

UNITS: dmnl/year

DEPRECIATION_RATE_IRRIGATION = 0.2

UNITS: dmnl/year

EFFECT_OF_MACHINES_ON_NON_RSPO_YIELD = GRAPH(ADEQUACY_OF_MACHINE_AVAILABILITY)

Points: (0.000, 0.6000), (0.100, 0.6051), (0.200, 0.6174), (0.300, 0.6466), (0.400, 0.7070), (0.500, 0.8000), (0.600, 0.8930), (0.700, 0.9534), (0.800, 0.9826), (0.900, 0.9949), (1.000, 1.0000)

UNITS: dmnl

EFFECT_OF_NON_RSPO_KNOWLEDGE_ON_YIELD = GRAPH(NONRSPO_KNOWLEDGE)

Points: (0.000, 0.6000), (0.100, 0.6051), (0.200, 0.6174), (0.300, 0.6466), (0.400, 0.7070), (0.500, 0.8000), (0.600, 0.8930), (0.700, 0.9534), (0.800, 0.9826), (0.900, 0.9949), (1.000, 1.0000)

UNITS: dmnl

EFFECT_OF_WATER_AVAILABILITY_ON_YIELD = (RAINFALL_PER_HA+WATER_FROM_IRRIGATION_PER_HA_NON_RSPO)/WATER_REQUIRED_FOR_CULTIVATION

UNITS: dmnl

EXPENSES_NON_RSPO = MIN(TOTAL_EARNINGS_NON_RSPO_FARMERS, OTHER_HOUSEHOLD_EXPENDITURE+PRODUCTION_COST_NON_RSPO)

UNITS: ghs/year

HOUSEHOLD_EXPENDITURE_PER_HA = 1000

UNITS: ghs/ha/year

IDEAL_PRODUCTION_AND_HARVESTING_MACHINES_PER_HA = 1

UNITS: machine/ha

INITIAL_IRRIGATION_INFRASTRUCTURE = 4000

UNITS: ghs/hectares

INITIAL_KNOWLEDGE_NON_RSPO = 0.3

UNITS: dmnl

INITIAL_MACHINES = 100

UNITS: machines/ha

IRRIGATION_CAPACITY_PER_GHS = 0.1

UNITS: Hectares*Millimeters/(ghs*Years)

LOANS_FROM_THE_SCHEME = 10000

UNITS: ghs/year

MAXIMUM_KNOWLEDGE_NON_RSPO = 1

UNITS: dmnl/year

NON_RSPO_FARMERS_YEILD = (.YIELD_POTENTIAL_NON_RSPO*3)*EFFECT_OF_WATER_AVAILABILITY_ON_YIELD*EFFECT_OF_NON_RSPO_KNOWLEDGE_ON_YIELD*EFFECT_OF_MACHINES_ON_NON_RSPO_YIELD

UNITS: tonnes/ha/year

OTHER_HOUSEHOLD_EXPENDITURE = .NON_RSPO_LAND*HOUSEHOLD_EXPENDITURE_PER_HA

UNITS: ghs/year

PALM_OIL_SELLING_PRICE_PER_ton = 10000

UNITS: ghs/tonnes

PRODUCTION_COST_NON_RSPO = .PALM_OIL_PRODUCTION_BY_NON_RSPO_FARMERS*PRODUCTION_COST_PER_TON

UNITS: ghs/year

PRODUCTION_COST_PER_TON = 3000

UNITS: ghs/tonne

RAINFALL_PER_HA = 1200

UNITS: mm/year

SAVINGS_NON_RSPO_FARMERS = TOTAL_EARNINGS_NON_RSPO_FARMERS-EXPENSES_NON_RSPO

UNITS: ghs/year

SAVINGS_PER_HA_NON_RSPO = SAVINGS_NON_RSPO_FARMERS/.NON_RSPO_LAND

UNITS: ghs/(Hectares*Years)

SHARE_OF_EARNING_TO_TRAINING = 0.0001

UNITS: dmnl

SHARE_OF_INVESTMENTS_TO_IRRIGATION_INFRASTRUCTURE_NON_RSPO = 0.5

UNITS: dmnl

TIME_TO_DEPRECIATE = 5

UNITS: dmnl

TIME_TO_PURCHASE = 2

UNITS: dmnl

TOTAL_EARNINGS_NON_RSPO_FARMERS = PALM_OIL_SELLING_PRICE_PER_ton*.PALM_OIL_PRODUCTION_BY_NON_RSPO_FARMERS

UNITS: ghs/year

TRAINING_DURATION_NON_RSPO = 1

UNITS: dmnl/year

TRAINING_INCENTIVES = SHARE_OF_EARNING_TO_TRAINING*SAVINGS_NON_RSPO_FARMERS

UNITS: ghs/year

TRAINING_INTENSITY_OF_NON_RSPO_FARMERS = GRAPH(TRAINING_INCENTIVES)

Points: (0.000, 0), (0.100, 0.001263), (0.200, 0.004341), (0.300, 0.01165), (0.400, 0.02676), (0.500, 0.05), (0.600, 0.07324), (0.700, 0.08835), (0.800, 0.09566), (0.900, 0.09874), (1.000, 0.1)

UNITS: dmnl/year

TRAINING_SWITCH_NON_RSPO = 1

UNITS: dmnl/year

WATER_FROM_IRRIGATION_PER_HA_NON_RSPO = IRRIGATION_INFRASTRUCTURE_PER_HA_NON_RSPO*IRRIGATION_CAPACITY_PER_GHS

UNITS: Millimeters/Years

WATER_REQUIRED_FOR_CULTIVATION = 1500

UNITS: mm/year